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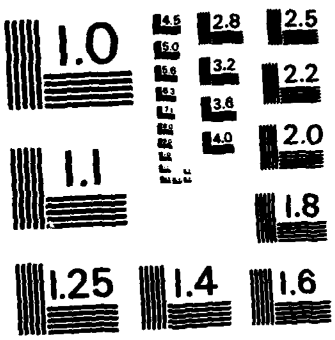
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US Army Corps
of Engineers
Engineer Institute for
Water Resources

Influence of Price and Rate Structures on Municipal and Industrial Water Use

June 1984

Contract Report 84-C-2

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This report documents over 50 substantial studies of the response of municipal and industrial water use to price in an attempt to correct the poorly understood phenomenon of the sensitivity of water use to price. Most likely price elasticity ranges are given for non-seasonal and seasonal residential water use; average residential water use; and reported elasticities for industrial and commercial water use.

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INFLUENCE OF PRICE AND RATE STRUCTURES ON MUNICIPAL AND INDUSTRIAL WATER USE

by

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A Report Submitted to the

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I. INTRODUCTION

THE ROLE OF PRICE

The efficient planning and management of water supply systems is based on a thorough understanding of the use of water and the factors which give rise to it. Forecasting, in particular, requires that the major factors (explanatory variables) be identified and their relationships to water use expressed in quantitative terms. Predictions of future values of explanatory variables, then, can be used to obtain predictions of future levels of water use.

The principal water use explanatory variables are well known, and have been described in other reports (Dziegielewski et al. 1981; Boland et al. 1981; and Boland et al. 1983). In the case of residential water use, for example, they include number of households, population per household, household income, property value, irrigable area, climate, and other factors. Industrial water use is explained by employment, industrial output, recycle ratio, and so forth.

Individual factors vary in importance. Stated in statistical terms, each factor is capable of explaining some fraction, large or small, of the total variance in water use. A factor such as number of residential households, which explains a large fraction of the variance, receives high priority for inclusion in forecasting models. To omit such a factor would be to risk serious error in estimates of future water use. As forecast accuracy becomes more important, and the forecasting method becomes more detailed, additional factors are included. These factors explain progressively less variance in future water use, and, in most cases, their potential contribution to overall accuracy declines accordingly.

While the fraction variance explained is an important consideration in choosing variables for forecasting models, it is not the sole criterion. The degree to which the explanatory variable itself changes in the future is also relevant. For example, irrigable area has been shown to be an important factor in explaining seasonal residential water use. If irrigable area is not expected to change (lot and building sizes remain constant), it may not be necessary to include this factor in the forecast model. Similarily, a factor which explains a small fraction of the variance, but is prone to large fluctuations in value, may be essential to an accurate forecast.

The price of water falls into the latter category. Price explains relatively little variance in water use (compared to such variables as number of households, population per household, climate, etc.). Yet variations in price have been responsible for significant shifts in use levels. Unlike most other factors, price can both increase and decrease and is capable of large and abrupt change. These characteristics give price, as a forecasting parameter, importance beyond its basic explanatory power.

Interest in the relationship between price and water use goes beyond its importance to forecasting. Of all the factors which explain water use, price is frequently the only one within the power of the water supply agency to change (the only decision variable). Changes in water rate level or design alter the prices which users face at the margin and thereby alter the level and pattern of water use. Understanding these interactions is essential to effective rate-making policy as well as supply planning.

Because of the nature of the relationship between price and water use, as well as the abrupt shifts in price which sometimes occur, adjustments to price change are not instantaneous. A change in price brings forth a slow and steady change in water use, which is complete after a period of time ranging up to ten years. Since this adjustment process rarely ends before the next price change occurs, special statistical techniques are often needed to observe the effect of price on water use.

PURPOSE OF THIS REPORT

The characteristics of price as a water use explanatory variable render it uniquely important to water use forecasting, and of considerable interest in other water supply management activities. Price is also capable of large and abrupt changes, and is often associated with a slow and complex response. For all of these reasons, the literature on price and water use probably exceeds, in size and elaboration, the collected discussion of any other single topic pertaining to water demand.

In spite of a relatively large number of useful studies of the effect of price on water use, published summaries have usually failed to reflect the detailed information available or to synthesize that information in a way which is helpful to practitioners. A typical summary table is contained in a previous Corps document (Baumann et al. 1979, 37-39). This table, based on several previously published compilations, simply lists the bare results of 29 previous studies, with minimal information on the type of relationship studied. The results vary widely (elasticities range from 0.00 to -1.41), but no explanation of the cause of this variation is offered.

The casual reader of these summaries could easily draw the conclusion that the sensitivity of water use to price is an uncertain and poorly understood phenomenon. This report is intended to correct that impression. Sufficient work has been completed in the last thirty years to delineate price responses for at least some categories of water use with considerable generality and consistency, as shown in Chapter II. The subsequent chapters discuss the methods and the results of more than 50 studies, organizing the information in a form that will permit forecasters and planners to make useful estimates of probable price effects under a range of local conditions.

The third chapter outlines the major theoretical and statistical considerations in developing and interpreting estimates of the price elasticity of water demand. The fourth chapter discusses the methods used to select, analyze and annotate reports of previous studies; the fifth chapter presents the results of that analysis. A detailed annotated bibliography, which presents a wide range of study results in a standard form and notation, is also provided.

II. CONCLUSIONS

1. Literature

The literature contains more than 50 substantial studies of the response of municipal and industrial water use to price. These include a single study from 1926, followed by some few studies published in the late 1950s and early 1960s. Starting in the later 1960s, interest in this subject increased noticeably, and the number and quality of published studies began a steady increase. The work of Howe and Linaweaver (1967) has long served as a model of high quality analysis, although most articles published since 1980 meet equally high standards of quality.

2. Statistical Deficiencies

Published studies provide results which are subject to a number of qualifications because of statistical deficiencies. These deficiencies originate in sample selection, model specification, choice of explanatory variables, choice of price variable, and level of aggregation. Most studies reviewed gave evidence of at least some difficulties in one or more of these areas.

3. Residential Winter (Nonseasonal) Water Use

Of the available studies of residential winter water use, only one (Howe 1982) appears to be substantially free of statistical deficiency. The results of other studies, after consideration of probable errors or deficiencies, are consistent with the Howe result.

MOST LIKELY ELASTICITY RANGE	(LONG RUN)	0.0 to -0.10
	(SHORT RUN)	n/a

4. Residential Summer Water Use

Available studies support the Howe and Linaweaver (1967) finding of significant differences in price response east and west of the 100th meridian, with respect to summer water use. One substantially reliable estimate of summer season elasticity is available for the eastern U.S.

(Howe 1982). Other studies, after consideration of probable statistical deficiencies, are consistent with this result. No estimates are available for western U.S. summer season elasticities.

MOST LIKELY ELASTICITY RANGE		
(LONG RUN)	Eastern U.S.	-0.50 to -0.60
	Western U.S.	n/a
(SHORT RUN)	Eastern U.S.	n/a
	Western U.S.	n/a

5. Residential Seasonal (Sprinkling) Water Use

As in the case of summer season use, a significant difference is expected between estimates for the western and those for the eastern U.S. All available studies contain at least some deficiencies. It is believed that most resulting errors are upward in direction (estimates are too elastic).

REPORTED ELASTICITY RANGE		
(LONG RUN)	Eastern U.S.	-1.30 to -1.60 *
	Western U.S.	-0.70 to -0.90 *
(SHORT RUN)	Eastern U.S.	n/a
	Western U.S.	n/a

* Study contains statistical deficiencies which may lead to error in the price elasticity estimates.

6. Residential Average Water Use

The elasticity of average annual residential use reflects (approximately) an average of the winter and summer price responses (or, seasonal and nonseasonal responses). Since summer season responses vary spatially, and the importance (weight) of the summer season varies with climate, results for average water use are not expected to be as reliable as those for narrower definitions of water use.

Most studies in the literature address residential average water use. Only a few of these are substantially free of error from one source or another, however. The studies which contain statistic deficiencies are consistent, after consideration of the probable direction and magnitude of resulting errors, with the unbiased studies.

MOST LIKELY ELASTICITY RANGE	
(LONG RUN)	-0.20 to -0.40
(SHORT RUN)	0.0 to -0.30

7. Industrial Water Use

Very little attention has been given to the price response of industrial customers of municipal water systems. Available studies suffer from deficiencies of various types, but do show significant differences among the various categories of industrial user. Studies of aggregate industrial use show, as expected, considerable variation from place to place as the mix of industrial use changes. In general, industrial water use is more elastic than residential use.

REPORTED ELASTICITY RANGE (LONG RUN)	
Individual categories	-0.30 to -6.71 *
Aggregate industrial	-0.50 to -0.80 *
(SHORT RUN)	
Individual categories	n/a
Aggregate industrial	n/a

* Study contains statistical deficiencies which may lead to error in the price elasticity estimates.

8. Commercial Water Use

The literature contains a single study (Lynne et al. 1978) of the price response of commercial water users, based on cross-sectional data from Miami, Florida. That study contains statistic deficiencies of various kinds, but does show significantly different elasticities for various categories of commercial use. This suggests that aggregate commercial/institutional studies, were they available, would show considerable variation in price response from place to place.

REPORTED ELASTICITY RANGE (LONG RUN)	
Individual categories	-0.20 to -1.40 *
Aggregate commercial	n/a
(SHORT RUN)	
Individual categories	n/a
Aggregate commercial	n/a

* Study contains statistical deficiencies which may lead to error in the price elasticity estimates.

III. PRICE ELASTICITY OF DEMAND

DEFINITION

The Demand for Water

Water is used for many purposes, ranging from human consumption (drinking) to irrigating lawns and gardens. While it is sometimes argued that water is uniquely essential to human life, the quantity required to sustain life is small (less than two liters/person/day) and can be easily supplied by means other than public distribution systems (in food, as bottled water or soft drinks, etc.). Water distributed by public systems, therefore, is an economic good like any other. Water is purchased and used in a way not fundamentally different from the consumption of bread or gasoline or any other staple commodity.

The quantity of water allocated to each use is affected by a number of factors or explanatory variables; when all uses are considered, a relatively large number of explanatory variables can be found to have some influence on the level of water use. There are two general categories of explanatory variables: (1) those which determine the need for water and (2) those which determine the intensity of use of water. "Need" variables include population served, number of households, industrial employment, etc. The presence of these factors indicates that water-using activities are occuring and that some water will be required. It is not clear from evidence of "need" alone how much water will actually be used.

The remaining variables determine intensity of use and include such factors as income (ability to pay for water), conservation practices (willingness to substitute inconvenience or other inputs for water use), and price (willingness to pay for water). For a given set of water-using activities ("need"), water use will increase with increasing income, decrease with increasing conservation activity, and decrease with increasing price.

Economists define the demand for water as the relationship between water use and price, when all other factors are held constant. Demand is a negative functional relationship, illustrated by the demand curve, shown as figure III-1. This curve describes the relationship between price and water use for a single user. The demand imposed by each water user can be represented by a similar demand curve, and all such curves are expected to be negatively sloped (increased price results in decreased water use).

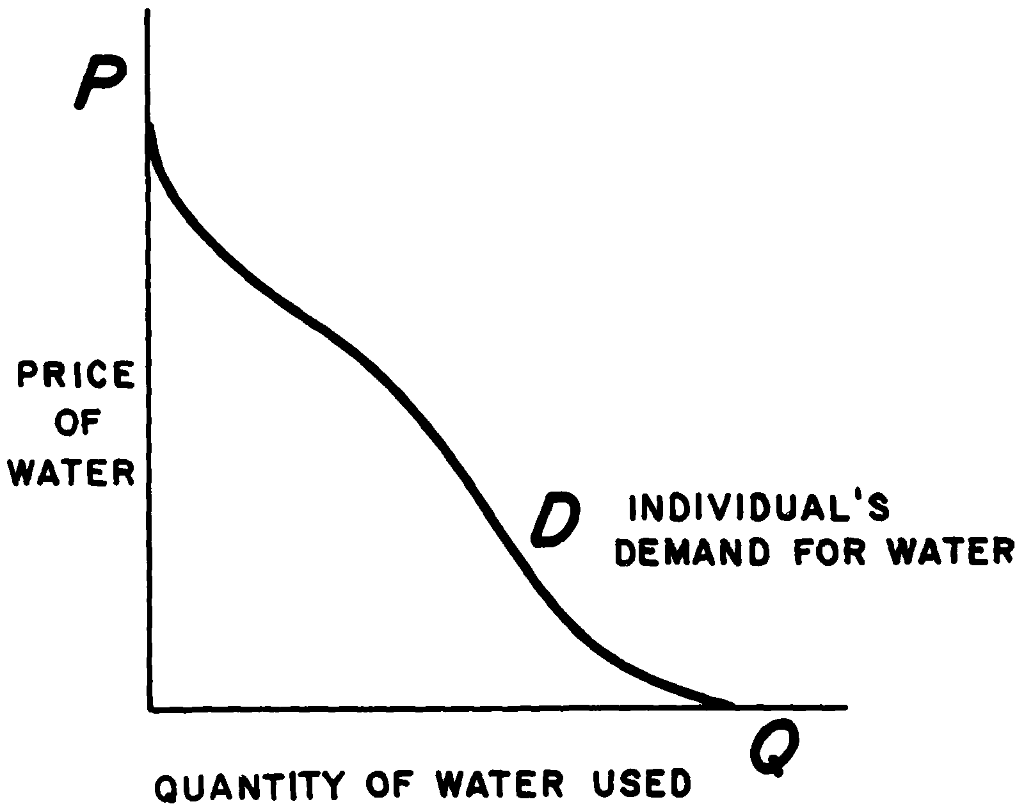

Figure III-1. Individual Demand Curve

When a number of users face a price which is uniform over the group, their individual demand curves can be summed horizontally to obtain an aggregate demand curve, as shown in figure III-2. The aggregate demand curve, usually called a market demand curve, is also negatively sloped. It can be seen that there is a price (P') at which no one will purchase water from the public system (they would prefer to obtain water by other means). Also, in the event that no price is set (price = zero), a finite quantity of water will be demanded (shown as Q'). Between these two extremes, the quantity of water demanded is determined by the price and the demand curve, if all other factors are held constant.

The shape and position of the demand curve are determined by the values of the other explanatory variables, including the "need" variables and income and conservation practices. The effect of increasing income is to shift the curve to the right (see figure III-3), so that the same price (P_0) would result in progressively larger quantities of water being used (Q_1, Q_2, Q_3). The effect of increasing conservation activity is to shift the curve to the left (figure III-4). Similarly, increasing the levels of the "need" variables will, generally speaking, move the demand curve to the right. All of these shifts may be accompanied by changes in the shape and slope of the demand curve, as indicated in figures III-3 and III-4.

Water supply planning rarely requires that the entire demand curve be known. More often, it is sufficient to know how specified incremental changes in explanatory variables will affect water use. In the case of price, this information is contained in the slope of the demand curve. The slope gives the incremental change in water use for an incremental change in price, at some position on the curve (see figure III-5).

Because of the units chosen for the axes of the demand curve (dollars per unit of water use, and units of water use), the slope of the curve has an inconvenient dimension (dollars per unit of water use squared). It is customary, therefore, to use a dimensionless measure of the relationship, found by dividing fractional (instead of incremental) change in water use by fractional change in price. This dimensionless measure is known as an elasticity, here called the price elasticity of water demand. It is defined for an arc of the curve, as shown in figure III-5, as:

$$\eta = \frac{\dfrac{Q_2 - Q_1}{Q^*}}{\dfrac{P_2 - P_1}{P^*}} \tag{1}$$

Where:

$$Q^* = \frac{Q_2 + Q_1}{2}$$

$$P^* = \frac{P_2 + P_1}{2}$$

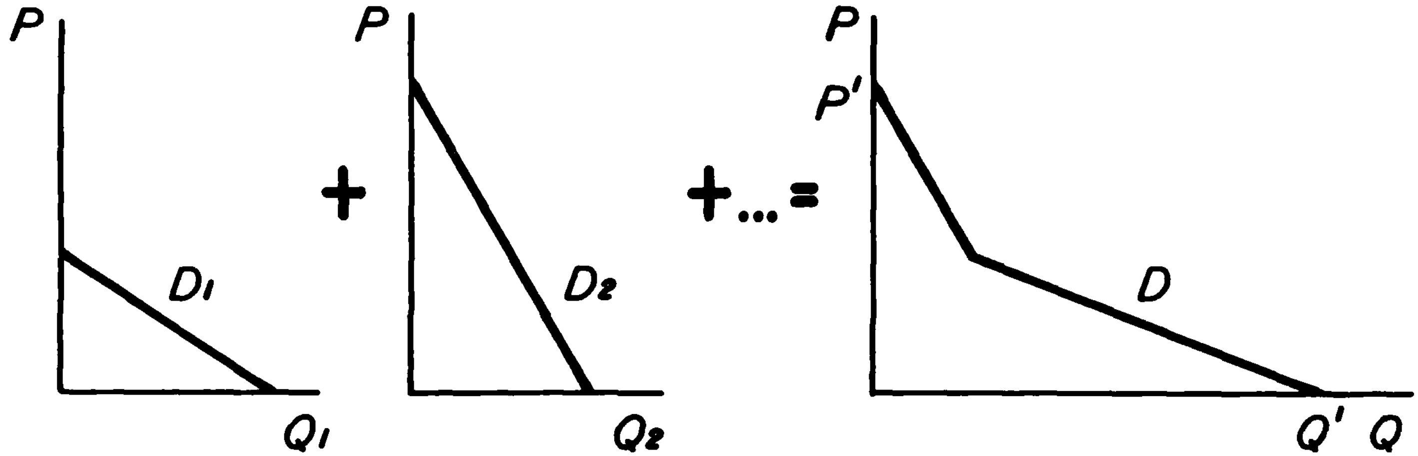

Figure III-2. Aggregate Demand Curve

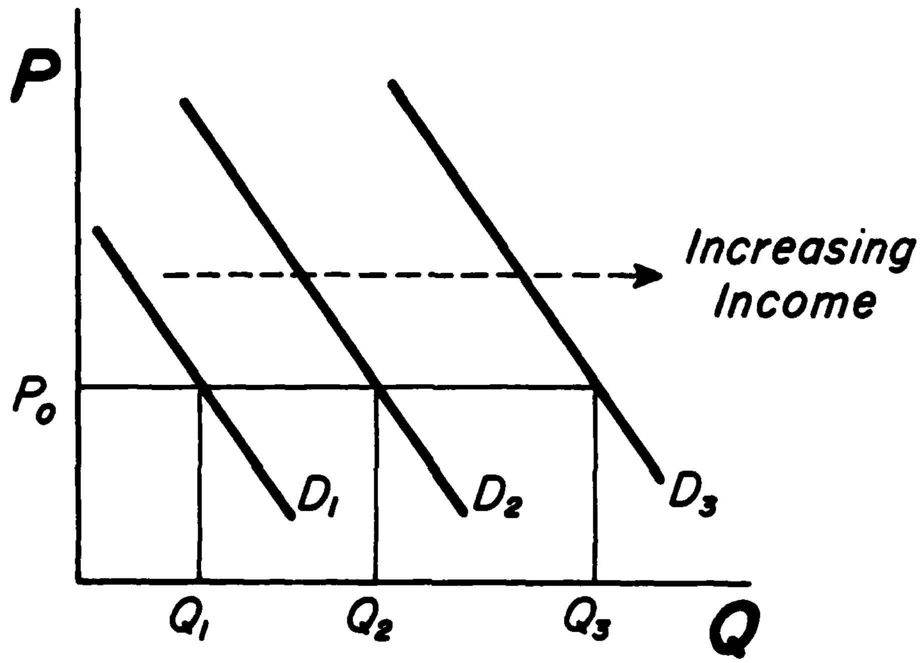

Figure III-3. Effect of Income on Demand

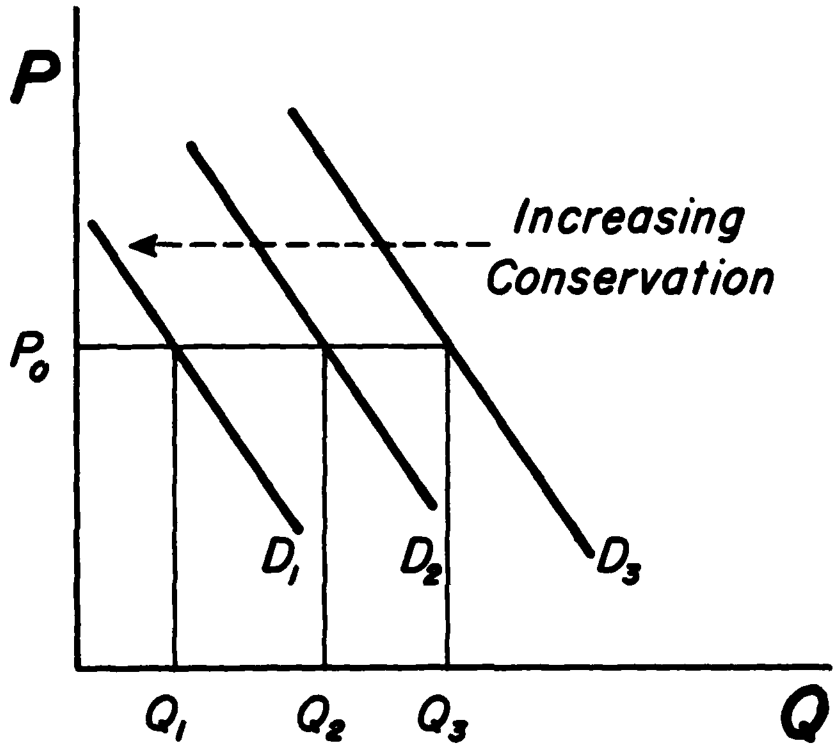

Figure III-4. Effect of Conservation Practices on Demand

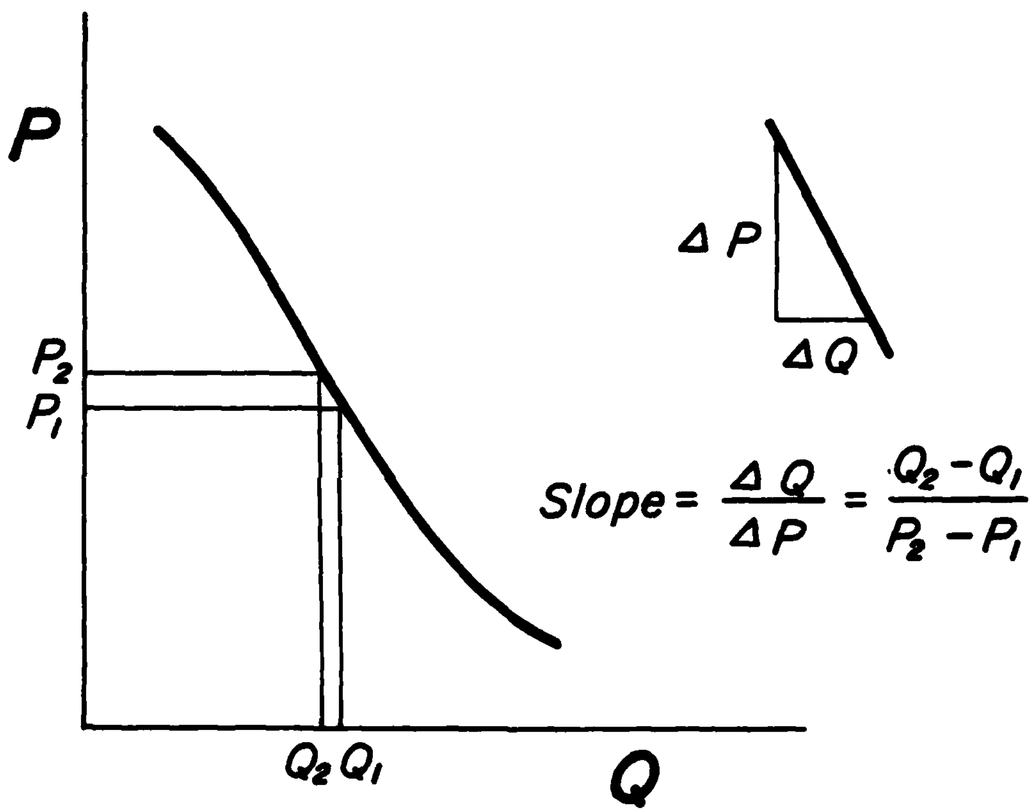

Figure III-5. Definition of Scope of Demand Curve

A more frequently used definition is based on the derivative of the demand function, and yields the elasticity at a specific point on the curve as follows:

$$\eta = \frac{dQ}{dP}\frac{P}{Q} \tag{2}$$

Where water use is a function of price and other variables, the ordinary derivative in (2) is replaced with a partial derivative:

$$\eta = \frac{\partial Q}{\partial P}\frac{P}{Q} \tag{3}$$

Both definitions give a dimensionless elasticity, which is expected to be a negative quantity (because the demand curve is negatively sloped). Price elasticity may be interpreted as the percentage change in quantity which would result from a one percent change in price. A price elasticity of -0.5, therefore, indicates that a 1.0 percent <u>increase</u> in price would be expected to result in a 0.5 percent <u>decrease</u> in quantity demanded (use). Conversely, a 1.0 percent <u>decrease</u> in price would produce a 0.5 percent <u>increase</u> in quantity demanded.

In order to distinguish different types of response to price, the following terms are used, depending on the magnitude of the calculated elasticity:

$\eta = 0.0$	perfectly inelastic (zero elasticity)
$0.0 > \eta > -1.0$	relatively inelastic
$\eta = -1.0$	unitary elasticity
$-1.0 > \eta > -\infty$	relatively elastic
$\eta = -\infty$	perfectly elastic (infinite elasticity)

In other words, demand is said to be relatively inelastic when quantity changes less than proportionately with price, and relatively elastic when quantity changes more than proportionately with price.

FACTORS INFLUENCING PRICE ELASTICITY

User Class

Water is used by many different types of users and for many different purposes. Each of these uses is associated with a (possibly different) set of explanatory variables, and may be affected differently by any of them. For purposes of analysis, water users are usually grouped into categories according to similarity of use types. Among the usual categories, or user classes, are single-family residential users, multi-family residential users, commercial and institutional users, industrial users, etc.

Because the relationships existing between explanatory variables and water use are possibly different for different user classes, the price elasticity of demand may be different as well. For this reason, studies are usually confined to a single, reasonably homogeneous user class. Results obtained for a specific user class are only applicable to that user class and not generally transferable to other groups of water users.

Where price elasticities of aggregate water use are reported, they approximate weighted averages of the elasticities of the component user classes. Since the weights vary from community to community according to the relative size of the classes, consistent estimates of elasticities of aggregate demand would not be expected.

Season

Even though user classes are defined to be as homogeneous as possible, there are still many different uses, affected by different explanatory variables, within each class. One method of further clarifying basic relationships is to separately analyze summer and winter (or, sometimes, seasonal and nonseasonal) water use within a class. This isolates the relatively more homogeneous winter (or nonseasonal) water use from the summer (seasonal) use, which includes various irrigation and outside uses.

Since the components of water use vary by season, the relevant explanatory variables, and their relationships with water use, vary as well. Price elasticity of demand, therefore, can be expected to vary between summer and winter (or seasonal and nonseasonal) water use.

Changes in Explanatory Variables

Since price elasticity of demand is defined at a particular point along a demand curve, a different value may be found at another point. If the demand curve is linear, for example, price elasticity would become more negative with increasing price, or less negative (closer to zero) with decreasing price (see figure III-6). Other equally plausible demand curves can be constructed with the same elasticity at every point (figure III-7), or with elasticity that becomes more negative with decreasing price. In general, elasticity may increase, decrease, or remain the same with decreasing price level.

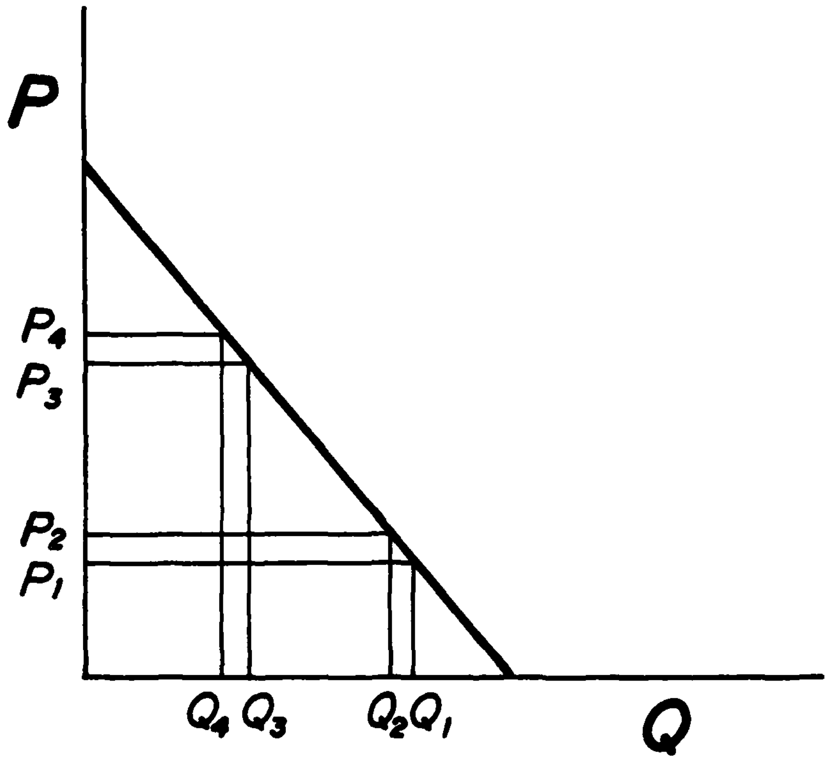

Figure III-6. Linear (Constant Slope) Demand Curve

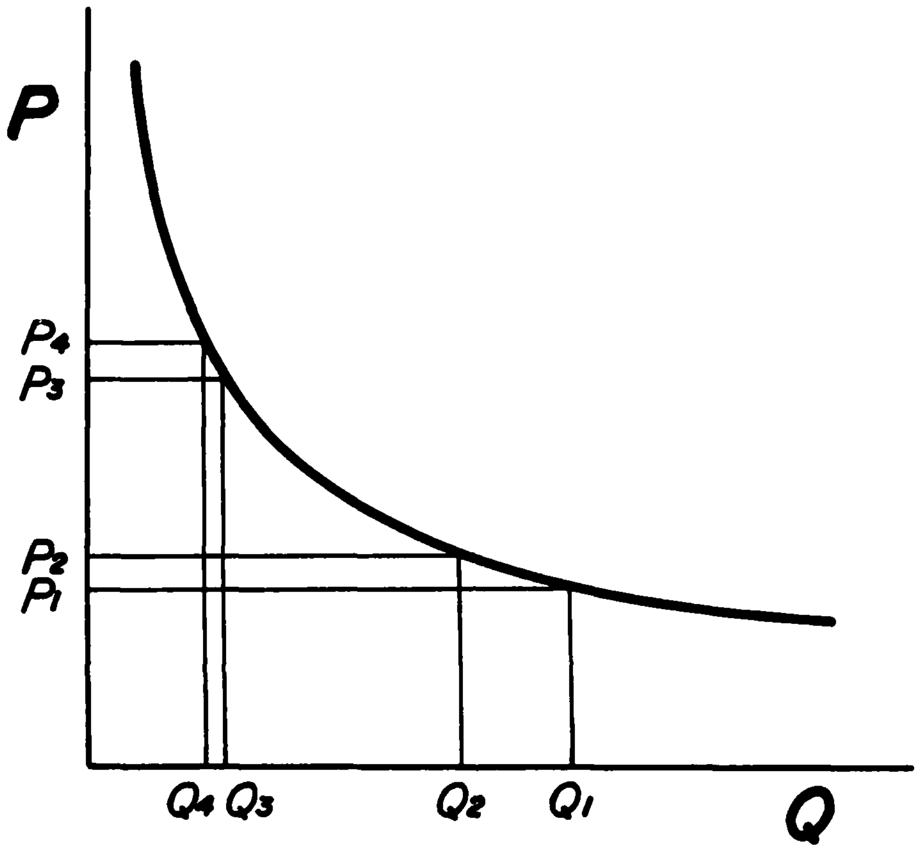

Figure III-7. Exponential (Constant Elasticity) Demand Curve

As noted above, demand curves depend upon the values of all other variables which determine water use. Figures III-3 and III-4 show this relationship for changes in income and conservation. Since the demand curves are changed in location and (possibly) shape, the value of price elasticity of demand may change as well. As in the case of price changes, there is no a priori assumption regarding the direction of elasticity changes in response to changes in other explanatory variables.

Long-Run vs. Short-Run

Elasticity also varies according to users' ability to make cost-effective adjustments in the use of related goods and in habits. In the case of water, this may include changes in the stock of water-using appliances, changes in landscaping, changes in irrigation practices, changes in domestic water use habits, etc. When the user is free to adjust any related good or behavior, the measured adjustment to price is described as a long-run elasticity. When one or more of the adjustments is not available for any reason, the adjustment is measured as a short-run elasticity.

Since adjustments to water price all require the passage of time, perhaps up to a decade (changes in the stock of major water-using appliances), long-run and short-run response become synonymous with long-term and short-term response, respectively. Although the terms have distinct meanings, they will be used interchangeably here.

It is expected that long-run responses will be more elastic (elasticity will be more negative) than short-run responses, although the difference may not be large in every case. It is also expected that a number of years may have to elapse before the long-run response can be presumed complete. The short-run response may be evident within weeks or months of the effective date of a price change.

Exceptions to these generalities should be noted. Changes in water price do not affect all users simultaneously. Typically, a change is announced to be effective for all meter readings or bills occurring after a certain date. Depending upon the meter-reading cycle and the billing lag, it may be four months or more before all customers actually receive a bill calculated according to the new rates.

Two different, and sometimes contradictory, responses may be observed. First, some users may react immediately on hearing of the new rate, even before it actually takes effect. This early response, the "announcement effect," is based on the expected, rather than actual, impact of the new rates. To the extent that the perceived impact is greater than the ultimate reality, the initial response may be greater than the later net adjustment. On the other hand, if the initial expectation underestimates the impact of the rates, the first response may be a smaller adjustment than that later adopted.

Second, other users may ignore or be unaware of the announcement, postponing their response until the first bill is received at the new rates. On seeing the impact of the rates, they may undertake a series of short-run, then long-run, adjustments as described above. Prior to the receipt of the first bill, however, there has been no change in water use patterns, even though the new price is in effect.

Attempts to observe short-run elasticities by means of time-series analysis over periods of less than one year may be confounded by these problems. Some users may have reacted to the announcement, sometimes overestimating and other times underestimating the actual impact of the price change. Other users may not react at all until the first bill arrives. These users' reactions are phased into overall water use statistics gradually, as the meters are read and the bills rendered. Observed progression from an initial short-run to a long-run response may, therefore, be distorted by the billing cycle.

EMPIRICAL ESTIMATION

Method

Estimates of price elasticity are obtained by econometric analysis of price-quantity data for samples of water users. In order to interpret the data, it is necessary to postulate the existence and the specific functional form of a demand function. This permits the parameters of the function to be estimated by statistical analysis, usually multivariate regression. Once the parameters are known, the price elasticity can be calculated, using one of the definitions provided above.

Since the various explanatory variables are typically and sometimes strongly correlated with each other, it is helpful to collect data on all important explanatory variables, so that as many related factors as possible can be included in the multivariate models. Also, since some explanatory variables may not be identified (because of oversight or lack of data), complete analysis requires consideration of the consequences of omitting relevant variables.

Demand models may be estimated from primary (collected for the purpose, perhaps using specially-installed meters) or secondary (collected for another purpose, usually billing) data. In all cases, water use data are usually of moderate-to-poor quality. Observations are frequently missing, and reported observations may be incorrect. Secondary data may contain estimates of water use (where meter readings were not available) and the period covered by each water use observation (the billing period) may be irregular.

Observations of explanatory variables may also suffer from quality problems. In some cases, the variables are poorly specified: the defined variable may be similar to, but not the same as, the variable actually presumed to affect water use. Residential households differ in their capacity to use water as a consequence of differences in life-style and available water-using appliances. This variable cannot be measured directly, so it is usually approximated by such variables as housing value, household income, number of appliances, educational attainment, socio-economic class, etc. While each of these may capture some part of the relationship of interest, none of them is identical to the true explanatory variable.

As a result of missing or poorly specified data, most empirical water use functions leave a significant fraction of the variance in water use unexplained. The problem is most noticeable for analyses based on cross-sectional data, where the missing variables are more likely to affect the results.

Functional Forms

As noted above, the form of the water use function must be specified in advance, so that its parameters may be estimated from the data. While many forms are possible, multivariate regression studies have usually focused on a few basic variants. These are based on the linear regression algorithm and differ only in the mathematical transformation used to achieve linearity. Other functional forms are occasionally used in conjunction with statistical techniques other than multivariate linear regression.

In describing the frequently used functional forms, the following notation will be used:

Q = quantity of water used

P = price of water

I = relevant measure of income

X = vector of other explanatory variables

z = error term

a, b, c, d = regression coefficents

$\overline{Q}$, $\overline{P}$, etc. = means of quantity, price, etc.

$\ln(\ )$ = natural (Napierian) logarithm

e = base of Napierian logarithms (= 2.7183...)

Linear Function

The simplest form of water use function uses no transformation at all; it is simply a multivariate linear relationship:

$$Q = a + bP + cI + dX + z \qquad (4)$$

When income and other explanatory variables are held constant, (4) reduces to the following expression for a linear demand curve:

$$Q = a' + bP \tag{5}$$

Where: $a' = a + c\overline{I} + d\overline{X}$

$\overline{z} = 0$

Price elasticity of demand, at any selected set of values for Q and P, is calculated from (4) as follows:

$$\eta = b\frac{P}{Q} \tag{6}$$

In most cases, the elasticity is calculated at the means ($\overline{Q}$, $\overline{P}$).

An example of a linear demand function can be found in Howe and Linaweaver (1967), who reported the following relationship for nonseasonal use by single-family households:

$$Q = 206 - 1.3P + 3.47I \tag{7}$$

The price elasticity of demand at the mean can be calculated if the mean values of water use and price are known. In this case, they are 206 gallons/day and 40.1 cents/1,000 gallons, respectively. The price elasticity is, therefore:

$$\eta = -1.30\,\frac{40.1}{206} = -0.2307 \tag{8}$$

Elasticities could be calculated at other points on the demand curve by supplying the corresponding values of Q and P. Since the elasticity depends upon the value of P (and, therefore, Q), however, differences between two independent studies may be explained, in part, by differing price levels. It could be helpful, in this case, to compare elasticities calculated at the same price level. Where the means differ significantly, however, the possible error associated with the estimate of the regression line increases rapidly for prices which diverge from the mean.

Log-Linear Model

A log-linear demand function is similar to a linear function, except that the dependent variable (Q) is replaced with its log transform (usually, its natural logarithm). This yields the following form:

$$\ln(Q) = a + bP + cI + dX + z \tag{9}$$

Taking the antilog of both sides would give:

$$Q = e^{a + bP + cI + dX + z} \tag{10}$$

Holding all factors except price constant yields the equation of the demand curve:

$$Q = a' * e^{bP} \tag{11}$$

$$\text{Where } a' = e^{a + c\bar{I} + d\bar{X}}$$

$$\bar{z} = 0$$

The price elasticity of demand, based on expression (10), is:

$$\eta = bP \tag{12}$$

An example of a log-linear model is offered by Gibbs (1978), who developed the following expression

$$\ln(Q) = 3.12 - 1.85P + 0.00004I \tag{13}$$

The elasticity, at the mean price of 28 cents/1,000 gallons, is:

$$\eta = -1.85P = -0.51 \tag{14}$$

As in the case of the linear model, price elasticity for the log-linear function is a function of price. In this case, however, elasticity is directly proportional to price.

Log-Partial Log Model

A further variant of the log-linear form includes log transforms for the dependent and some, but not all, of the right-hand-side (explanatory) variables. An example of this form is:

$$\ln(Q) = a + bP + c\ln(I) + d\ln(X) + z \tag{15}$$

The alternative form is:

$$Q = e^{a + bP + z} * I^c * X^d \tag{16}$$

The demand curve, holding I and X constant, would have the following form:

$$Q = a' * e^{a + bP} \tag{17}$$

Where: $a' = I^c * X^d$

$z = 0$

As in the case of the log-linear model, the price elasticity of demand is directly proportional to price:

$$\eta = bP \tag{18}$$

Foster and Beattie (1979) provide an example of a log-partial log function:

$$\ln(Q) = -1.3895 - 0.1278P + 0.4619 \ln(I) + d \ln(X) \tag{19}$$

The price elasticity, calculated at the mean price of $3.67/1,000 gallons, is:

$$\eta = -0.1278 * 3.67 = -0.469 \tag{20}$$

Double-Log Model

The final variant of this class of demand functions is a multivariate linear model with all variables replaced with their log transforms. The model has the following form:

$$\ln(Q) = a + b \ln(P) + c \ln(I) + d \ln(X) + z \tag{21}$$

This can also be written as:

$$Q = a' * P^b * I^c * X^d$$

Where: $a' = e^{a + z}$ (22)

The two-parameter demand curve (with other variables held constant) is:

$$Q = a'' * P^b \tag{23}$$

Where: $a'' = e^a * \bar{I}^c * \bar{Z}^d$

$\bar{z} = 0$

The price elasticity of demand of the double-log model has a very convenient form:

$$\eta = b \tag{24}$$

Elasticity, therefore, is constant and independent of the values of P or Q. It is not necessary to decide which value of P to use for the calculation, and results from independent studies can be more easily compared to one another.

An example of a double-log model can be found in Billings and Agthe (1980):

$$\ln(Q) = -7.36 - 0.267 \ln(P) + 1.61 \ln(I) - 0.123 \ln(D) + 0.0897 \ln(W) \tag{25}$$

This model can also be written:

$$Q = 0.0006362 * P^{-0.267} * I^{1.61} * D^{-0.123} * W^{0.0897} \tag{26}$$

The value of the price elasticity of demand is, therefore:

$$\eta = -0.267 \tag{27}$$

OTHER ISSUES

Bias

Multiple regression demand models of the type shown above, provide valid estimates of the price elasticity of demand provided that certain conditions are met. These include:

1. The functional form is properly chosen.

2. The variance of the dependent variable is unrelated to the values of the explanatory variables (homoscedasticity).

3. The dependent variable (given values for the explanatory variables) is normally distributed.

4. The residuals are not autocorrelated.

5. All significantly correlated explanatory variables are included.

6. All included explanatory variables are correctly specified.

Failure to satisfy these requirements may affect the efficiency with which the price coefficient is estimated (resulting in incorrect measures of reliability or goodness of fit), or it may affect the value of the price coefficient itself. In the latter case, the estimate of the coefficient is systematically in error, or <u>biased</u>.

Bias in the price coefficient can arise from a number of sources, but the most frequent causes include improperly defined or selected data samples, omission of one or more variables which are correlated with water use and collinear with price, and incorrectly specified price variables.

Price Variable Specification

While most economic goods are sold to consumers at well-defined prices, water is priced by means of relatively complex rate schedules. These schedules may include a number of fixed charges--including assessments, service charges, minimum charges, etc.--as well as a number of variable charges. The variable charges may differ from one group of users to another (class rates), from one block of use to another (decreasing and increasing block rates), or from one season to another (seasonal rates).

Economic theory states that the price which affects the level of use is the price paid at the margin, i.e., for the last unit used. Depending upon the structure of rates, this price may vary from user to user, or from time to time for the same user. It may be difficult or impossible to determine the marginal price associated with each observation of water use. For example, when water use is aggregated over a number of users who face block-type rates, marginal price data are inevitably lost. For these reasons, many studies rely on measures of average price, sometimes calculated as total revenue from charges divided by total water sold.

When time-series data are used, price data must be deflated to a constant dollar measure, using some suitable index. National or local consumer price indices are most often used for this purpose. In the case of seasonal rates, it may be necessary to develop measures of price which account for lags in the billing cycle, and the perception of users regarding cyclical changes in price.

The correct specification of price is of fundamental importance in estimating price elasticities. Even where price has been correctly specified, however, the characteristics of the rate structure may introduce bias. When decreasing block designs are used, for example, the marginal price decreases as more water is used. This insures a negative functional relationship between price and use, even if customers are completely insensitive to price. Data collected from individual customers facing such a rate will, therefore, inevitably overestimate price elasticity.

Another characteristic of block-type rate structures is a relatively large gap between marginal price and average price. Customers served by different utilities, on different rate schedules, may pay the same marginal price but quite different total bills (average prices). Such customers would not be expected to exhibit identical water use, other things being equal, either because of different perceptions of price or, more likely, because of different residual incomes. In order to deal with this problem, a special construct, Nordin's bill difference variable (Bell Journal of Economics 7 [1976]:719-21), is used to measure differences in residual income. The bill difference variable is defined as:

$$D = TB - (Q^*P_m) \tag{28}$$

Where: TB = total bill during billing period

Q = total water use during billing period

P_m = effective marginal price of water during billing period

Using the bill difference variable and marginal price, the demand function takes the following form:

$$Q = a + bP_m + cI + dX + eD \tag{29}$$

The calculation of price elasticity must be altered, however, since D is itself a function of price. An example of this calculation is provided by Howe (1982). He describes a decreasing-block design with a fixed service charge and a customer whose use extends to the second block, where:

$$D = TB - (Q^*P_m) = [SC + Q^1 * P_{m1} + (Q - Q^1)^*P_m] - Q^*P_m \tag{30}$$

Where: SC = service charge per billing period

Q^1 = quantity of water allowed in first block

P_{m1} = marginal price in first block

P_m = marginal price in second block

which simplifies to:

$$D = SC + Q^1(P_{m1} - P_m) \tag{31}$$

Substituting (31) into (29), taking the partial derivative with respect to P_m, and using the definition of price elasticity given as expression (3), the following is obtained:

$$\eta = \frac{Q}{P_m}\,\frac{P_m}{Q} = (b - dQ^1)\,\frac{P_m}{Q} \tag{32}$$

If elasticity is to be estimated at the means, the appropriate values must be provided for price and quantity. Note that the size of the first block (Q^1) must be expressed as units of use per billing period to agree with the dimension of regression coefficient d.

Howe obtained the following expression for a similar application (for users in the second block of a decreasing-block rate structure):

$$Q = 234.0 - 127.9\ P_m + 4.04I - 7.20D \tag{33}$$

Where Q^1 = 12.75 units (1,000 gallons) per billing period, and the means of water use and second block price are 261 gallons/day/dwelling unit and \$0.40/1,000 gallons, respectively, the elasticity at the means is:

$$\eta = [-127.9 - 12.75*(-7.20)] * \frac{0.40}{261} = -0.055 \tag{34}$$

It should be noted that if the bill difference variable had been omitted (and the same coefficient obtained for the price term), the elasticity would have been estimated at -0.196, a significant overestimate.

Collinearity

Explanatory variables are chosen because they are believed to be correlated with water use. Unfortunately, when two or more explanatory variables are used in the same water use model, they are often correlated with each other (collinear). When collinearity is pronounced, the first variable to enter the regression equation will assume a coefficient which expresses its own relationship to water use and, to some degree, the relationship of the correlated variable. Bringing the second variable into the equation may make only a small improvement in the fraction of variance explained, but the value of the coefficient of the first variable will change markedly. Collinearity creates ambiguity regarding the meaning and significance of the coefficients of collinear variables and causes those coefficients to be unstable.

Time-Series Analyses

When water use data consist of successive observations over time for the same users, collinearity may lead to a special set of problems. Most, if not all, explanatory variables are strongly correlated with time. Since all observations in a time-series analysis have the time sequence in common, they are likely to be highly correlated with each other. The possibility of biased or inefficient coefficient estimates is enhanced by the fact that even borderline explanatory variables, not considered for inclusion in the model, may be strongly correlated with the variables that are included.

Problems with missing variables may be detected by analyzing the regression residuals for serial correlation. Statistical tests are available (e.g., the Durbin-Watson test) to identify significant serial correlation. In the event of positive results, adjustments should be made to the regression model to minimize bias in coefficient estimates and in significance tests.

IV. RESEARCH METHOD

LITERATURE SEARCH

A review of the literature was carried out in order to identify significant studies of the effects of price, rate structures, and pricing policies on municipal and industrial water use.

Computer searches of two independent data bases were conducted in order to prepare the initial listings of studies to be reviewed. The first data base was the Selected Water Resources Abstracts developed and maintained by the Water Resources Scientific Information Center of the U.S. Department of the Interior. The second search used the data base of the American Water Works Association, maintained by the AWWA Library in Denver, Colorado. A list of about 300 publications was compiled from the printout of abstracts identified through the appropriate key words. Independently, the 1980-84 issues of the water resource journals, including Land Economics, Journal of AWWA, Water Resources Research, Water Resources Bulletin, and the Journals of the ASCE were reviewed for the most recent publications.

A secondary compilation of reference listings was made by inspecting the bibliographies and citations in most recent publications and comparing them to the listing of publications discussed above.

INITIAL EXCLUSIONS

The three hundred titles included on the listing compiled during the literature search stage were individually inspected in order to determine whether they met two initial criteria for inclusion. These were:

1. whether the publication reported an empirical study of water use; and

2. whether any price-related variable was included in the data base and subsequently used as an explanatory variable in an estimated demand function.

The first criterion was used to eliminate secondary assessments of the effects of price on water use. Such publications, although often containing valuable discussion, are not intended for inclusion in the present report. This criterion allowed selection of those publications which had actual data to support their findings. The second criterion led to the exclusion of additional studies which either concentrated on the estimation of "requirements" models or which failed to report a significant relationship between water use and price. Frequently these studies suffered from study design defects such as improper specification of price variables or insufficient variance of price in the sample.

The publications which met the above criteria were further subdivided into those using sectoral water use (such as residential, commercial, institutional, industrial, and unaccounted) as the dependent variable, and those which used aggregate municipal production or sales records in the specification of the dependent variable. The price elasticity of aggregate municipal demand for water cannot be interpreted in any meaningful way because of the unknown weights of the individual sectors, each responding to price changes in a different way. While average response to price of a homogeneous group of residential users may be safely interpreted as a meaningful measure of price elasticity in residential sector, the corresponding average reponse for the aggregate of residential and industrial users will not permit such a conclusion. A significant reduction in water use by residential customers in response to price changes, accompanied by negligible changes in use by other sectors may be undetectable by measurements of total municipal water sales, especially when industrial sector strongly contributes to total municipal use. Still, the changes in revenue may be considerable especially when decreasing block tariffs are practiced. As a result, the studies of aggregate municipal water demand were given a second priority for inclusion into the pool of annotated studies, i.e., no attempt was made to include all such studies.

FORMAT OF ANNOTATIONS

Fifty-three annotations are included in the appendix to this volume. Each annotation includes three main elements: (1) bibliographical documentation; (2) the abstract in a narrative form; and (3) a summary of data base information. These parts are described in greater detail below.

The bibliographical documentation is prepared according to the format used by Water Resources Research, a leading journal in the field. The bibliographical style of this journal was also selected for previous reports prepared for the IWR because of its clarity and wide spread use (with only minor modifications) by other periodicals in the water resources discipline.

The narrative abstract includes five basic elements: (1) the brief statement describing the specific objectives, location, and time period of the study; (2) a short description of the data characteristics; (3) the results transformed by the abstractor into an explicit mathematical form such as a multivariate linear equation; (4) definition of unconventional explanatory variables and their units of measurement; and (5) a closing paragraph containing a concise statement of major findings related to price of water and, when applicable, comments on the appropriateness of statistical tools used by the authors. Items (1) and (2) are often combined into the first paragraph in order to improve the readability of the abstract.

Finally, the last part of the annotation presents specific information in the form of a checklist. The pertinent information is grouped into two categories: (1) characteristics of the study area and (2) definition of water use data base. The detailed description of each item is given in table IV-1. Each checkpoint is selected to convey information required in final comparisons and analyses of price elasticities obtained in various studies without the need to consult the original report.

CROSS-REFERENCING CATEGORIES

In order to facilitate cross-referencing of the studies which meet a specified set of data characteristics, a system of codes characterizing the important elements of each study was developed. This coding system, referred to as the Data Base Information Code, is shown in table IV-2.

Since all the abstracts were prepared as document files on the Multimate word processor, any subset of annotations (files) can be easily identified through a document search utility using the codes as key words. For example, in order to compare residential water demand equations estimated from time-series data with those estimated from cross-sectional data, the appropriate two sets of studies may be identified by specifying the codes <U14,M11> and <U14,M12>, respectively. If only studies using marginal price as explanatory variables are desired, then an additional third code <M2Pms> can be specified. The code categories in table IV-2 represent those characteristics of the data in each study which might have some bearing on the estimates of price elasticity.

Table IV-1
DATA BASE INFORMATION

Study Area Data

Location and water users: city, SMSA, state, type and number of users.

Mean summer temperature: (T), normal, in degrees F.

Mean summer precipitation: (F), normal, in inches.

Mean summer evapotranspiration: (ET), normal, in inches.

Mean summer moisture deficit: M = (ET - 0.6F), summer evapotranspiration less effective summer precipitation.

Water rates: flat rate, uniform, increasing and decreasing block, mixed.

User sector: aggregate municipal, residential single-family, residential multi-family, all residential, commercial, institutional, commercial/institutional, industrial, public, unaccounted, all uses except unaccounted, all uses except industrial.

Area character: urban, suburban, metropolitan, rural, and other.

Water Use Data

Maximum number of cases: maximum number of cases subject to statistical analysis (for pooled time series and cross sectional data equal to number of time periods times number of users).

Type of measurement: primary, if measurements made for the purpose of the study; secondary, if measurements made for other purposes.

Measurement period: month/year to month/year of data.

Dependent variable: definition of water use in the estimated model(s).

Summer season definition: calender dates of the season when dependent variable specification includes seasonal water use.

Winter season definition: as above.

Estimating technique: ordinary least squares (OLS), generalized least squares, factor analysis, autoregressive and/or lagged models, Ridge regression.

Price variable specification: a precise definition of price-related variables (e.g. real marginal price for average user in the sample in $/1000 gallons).

Special circumstances: presence of special circumstances during sampling period (droughts, conservation programs, significant rate changes).

Minimum, maximum, and mean variable values: if reported, minimum to maximum and mean values for the dependent, price-related, and other significant variables used in the analysis.

Price elasticities: estimates are reported.

Table IV-2
DATA BASE INFORMATION CODE

D(nn) = WATER USE DATA

D1(n) = TYPE OF MEASUREMENTS
- D11 = primary, (made for the purpose of the study), individual users
- D12 = secondary, (made for other purposes), individual users (water bills)
- D13 = primary, groups of users with similar characteristics (master-metered areas)
- D14 = secondary, groups of users with dissimilar characteristics
- D15 = aggregate production records
- D16 = aggregate water sales

D2(n) = IDENTIFICATION OF DEPENDENT VARIABLE:
- D21 = monthly
- D22 = summer/winter division
- D23 = seasonal/non-seasonal
- D24 = annually
- D25 = other

D3(n) = PERIOD OF MEASUREMENT
- D31 = before 1950
- D32 = 1951-1955
- D33 = 1956-1960
- D34 = 1961-1965
- D35 = 1966-1970
- D36 = 1971-1975
- D37 = 1976-1980
- D38 = 1981-1985

D4(n) = WATER RATES
- D41 = flat rate
- D42 = uniform price (commodity charge)
- D43 = decreasing block
- D44 = increasing block
- D45 = mixed rates in multi-site data
- D46 = unknown or not applicable

M(nn) = WATER USE MODELS

M1(n) = DATA SET CONFIGURATION
- M11 = time series
- M12 = cross-sectional
- M13 = pooled time series and cross-sectional
- M14 = autoregressive moving average
- M15 = other

M2(code) = PRICE VARIABLE SPECIFICATION
- M2Pau = average price for all customers of utility
- M2Pas = average price for all users in sample
- M2Pac = average price for each user in sample
- M2Pms = marginal price for average user in sample
- M2Pmc = marginal price for each user in sample
- M2Das = Nordin's bill difference for average user in sample
- M2Dac = Nordin's bill difference for each user in sample

E(nn) = ERRORS AND SPECIAL CIRCUMSTANCES

E1(n) = SPECIAL CIRCUMSTANCES DURING SAMPLING PERIOD
- E11 = drought
- E12 = other water supply emergency
- E13 = conservation programs in effect
- E14 = water use restrictions in effect
- E15 = significant rate change
- E16 = significant service area change
- E17 = not reported

Table IV-2 (continued)

U(nn) = USER AND STUDY AREA CHARACTERISTICS

U1(n) = USER SECTOR
- U11 = aggregate municipal
- U12 = residential single-family
- U13 = residential multi-fumily
- U14 = all residential
- U15 = commercial
- U16 = institutional
- U17 = commercial/institutional
- U18 = industrial
- U19 = public
- U110 = unaccounted
- U111 = all uses except unaccounted
- U112 = all uses except industrial

U2(n) = STUDY AREA
- U21 = urban
- U22 = suburban
- U23 = metropolitan
- U24 = rural
- U25 = other
- U26 = unknown

U3(n) = AREAL SAMPLE
- U31 = single area
- U32 = multiple sites
- U33 = other configurations

U4(n) = MEAN SUMMER PRECIPITATION
- U41 = less than 5 inches
- U42 = 5 to 10 inches
- U43 = 10 to 15 inches
- U44 = 15 to 20 inches
- U45 = greater than 20 inches
- U46 = not applicable

U5(n) = MEAN SUMMER EVAPOTRANSPIRATION
- U51 = less than 10 inches
- U52 = 10 to 15 inches
- U53 = 15 to 20 inches
- U54 = greater than 20 inches
- U55 = not applicable

U6(n) = MEAN SUMMER TEMPERATURE
- U61 = less than 60 °F
- U62 = 60 to 64 °F
- U63 = 65 to 69 °F
- U64 = 70 to 74 °F
- U65 = greater than 75 °F
- U66 = not applicable

V. DISCUSSION OF RESULTS

SUMMARY OF FINDINGS

Scope of the Literature

There are more than 50 substantial analyses of water use/price data in the open literature. The earliest known study was published in 1926 by Leonard Metcalf, a prominent consulting engineer. Metcalf, using bivariate graphical analysis of a large cross-sectional sample, noted a strong negative relationship between per capita municipal water use and price.

No further work on this subject is evident until the late 1950s, when two studies of municipal water use (Seidel and Baumann 1957; and an unpublished seminar paper by Renshaw 1958); and one study of residential water use (Fourt 1958) appeared. These studies, predating general availability of high-speed digital computers, employed simple analytical methods and investigated relatively few explanatory variables.

During the 1960s, studies of the effect of price on municipal (aggregate) water use began to appear regularly. Four contributions are analyzed in this report (Gottlieb 1963; Gardner and Schick 1964; Flack 1965; Bain et al. 1966). Interest in the residential sector began to grow rapidly after 1967, when studies by Howe and Linaweaver, Ware and North, and Conley were published. The Howe and Linaweaver study, in particular, set still-existing standards for comprehensiveness and analytical sophistication. Turnovsky's influential analysis of price elasticity for both residential and industrial sectors (1969) also appeared about this time, as did Rees's (1969) work on industrial water use.

The literature expanded markedly during the 1970s. At least 15 studies of residential sector price elasticity were published in this decade, as well as five studies of the industrial sector and the single existing analysis of price response in the commercial water use sector (Lynn 1978). Five additional studies of municipal water use appeared. Four of these (Wong 1972; Young 1973; Sewell 1974; Morgan and Smolen 1976) analyzed time-series data for the first time, creating the opportunity (not expoited by these authors) of distinguishing between short-run and long-run price reponses.

As of the date of this report (1984), the present decade gives evidence of at least as much activity as the previous one. Two studies of municipal water use (both using time-series data), eight new studies of residential water use, and two analyses of the industrial sector are already in print. Overall, the apparent quality of these studies is much improved over the standards of the 1960s (the Howe and Linaweaver study was an exception to a general lack of rigor). Furthermore, most studies published since 1980 have incorporated basic improvements in the specification of the price variable, leading to much more reliable estimates of elasticity.

Altogether, this report reviews the results of 50 studies, which can be grouped as follows:

SECTOR	NO. STUDIES
Municipal (aggregate)	13
Residential	
Winter (domestic)	6
Summer or seasonal (sprinkling)	7
Combined	27
Total	28*
Industrial	9
Commercial	1
Total	50**

*Howe and Linaweaver 1967 did not consider combined residential use.

**Turnvosky (1969) and Ben-Zvi (1980) analyzed both residential and industrial sectors.

These represent essentially all published and adequately documented studies of sectoral (i.e., residential, commercial, industrial) water use, as well as a sampling of important analyses of municipal water use.

Municipal Water Use

Table V-1 lists, in summary form, descriptions of 13 studies of municipal water use. These studies provide, altogether, 32 estimates of price elasticity, ranging from -0.02 to -1.23, using data for periods from 1920 (Metcalf 1926) to 1977 (Hansen and Narayanan 1981). Some estimates of price elasticity are significant at customary levels of confidence (e.g., 0.05), others are not significant, and still others have no significance test reported (most studies published before 1970).

Studies of sectoral elasticity, reviewed below, confirm the existence of systematic differences in price response among the various sectors of municipal water use. Since total municipal use invariably includes two or more of the major sectors, municipal price response must reflect some

TABLE V-1. AGGREGATE MUNICIPAL DEMAND—EMPIRICAL STUDIES

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
1.	Metcalf-26	-0.65 n.r.	—	—	—	—	—	—	—	DL	29	—	—	Pau	29 waterworks systems the years 1920-1924 (calculated elasticity by Wong-72)
2.	Seidel-57	-0.12 n.r.	—	0.45	—	—	—	—	—	—	—	—	—	Pau	111 water systems from 1955 AWWA survey.
		1.00 n.r.	—	0.15	—	—	—	—	—	—	—	—	—	Pau	Elasticities calculated by Howe & Linaweaver
3.	Gottlieb-63	-1.23 n.r.	—	—	—	—	—	—	10-15	DL	19	0.67	2	Pau	Annual use in 19 Kansas towns (1952 cross-section)
		-0.67 n.r.	—	—	—	—	—	—	10-15	DL	24	0.72	2	Pau	Annual use in 24 Kansas towns (1957 cross-section)
4.	Gardner-64	-0.77	0.01	0.16	0.48	78	245	1412	14	DL	43	0.83	2	Pau	Annual per capita use in 43 water systems in northern Utah
5.	Flack-65	-0.12 n.r.	—	0.45	—	—	108	—	—	—	54	—	1	Pau	54 Western cities
		-1.00 n.r.	—	0.15	—	—	213	—	—	—	54	—	1	Pau	
6.	Bain-66	-1.10	0.17	—	0.69	38	—	421	8-15	DL	41	—	1	Pau	Average annual water use per capita in 41 California water systems

Legend: MD = moisture deficit (potential evapotranspiration less effective precipitation), inches;
f(X) = the functional form where L = linear, DL = double-logarithmic, and LPL = log partial log;
N = sample size;
R^2 = coefficient of determination;
n.r. = significance of price coefficient not reported;
— = information not available or not reported.
For explanation of price specifications see Table IV-1 and Table IV-2.

TABLE V-1. AGGREGATE MUNICIPAL DEMAND--EMPIRICAL STUDIES (continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
7.	Wong-72	-0.02 not sig.	--	--		--	--	--	9	DL	11	0.82	3	Pau	Per capita average use in Chicago (1951-1961 series)
		-0.28	--	--	--	--	--	--	0	DL	11	0.57	3	Pau	Per capita use in an aggregate of suburbs of Chicago (1951-1961 series)
		-0.53	--	--	--	--	--	--	9	DL	23	0.48	2	Pau	23 Chicago Sub. >25 thousand
		-0.82	--	--	--	--	--	--	9	DL	40	0.53	2	Pau	40 suburbs, 10-25 thousand
		-0.46	--	--	--	--	--	--	9	DL	25	0.38	2	Pau	25 suburbs, 5-10 thousand
		-0.27 not sig.	--	--	--	--	--	--	9	DL	15	0.29	2	Pau	15 suburbs, <5 thousand
8.	Young-73	-0.65	0.22	0.27	0.36	236	268	326	18	L	19	0.56	2	Pas	Annual water production in Tucson, Arizona (1946-1964 *time series*)
		-0.60	0.22	0.27	0.36	236	268	326	18	DL	19	0.60	2	Pas	
		-0.47 not sig.	0.22	0.27	0.36	236	268	326	18	L	7	0.64	2	Pas	Annual production for 1965-1971 time series
		-0.41 not sig.	0.22	0.27	0.36	236	268	326	18	DL	7	0.60	2	Pas	
9.	Sewell-74	-0.39	0.22	0.27	0.31	142	160	180	11	DL	17	0.80	4	Pas	Average per customer use in 17 water districts in Victoria Canada for 17 years (1954-1970)
		-0.46	0.22	0.27	0.31	142	160	180	11	L	17	0.79	4	Pas	

TABLE V-1. AGGREGATE MUNICIPAL DEMAND--EMPIRICAL STUDIES (continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
10.	Morgan-76	-0.44	--	--	--	--	--	--	10-17	L	396	0.68	4	Pau	Average monthly municipal use in 33 Southern Calif. cities (12 obs. in each)
		-0.45	--	--	--	--	--	--	10-17	L	165	0.45	4	Pau	Average monthly use in Nov.-March (approx. domestic use)
		-0.43	--	--	--	--	--	--	10-17	L	231	0.63	4	Pau	Average monthly use in April-Oct. (domestic & sprinkling)
11.	Clark-77	-0.63	0.20	0.66	1.30	32	91	188	9-11	L	22	0.45	1	Pms	Average per capita demand in 22 water systems in Cincinnati, Ohio
		-0.60	0.20	0.66	1.30	32	91	188	9-11	DL	22	0.38	1	Pms	
12.	Carver-80	-0.05	0.28	--	1.55	138	--	1429	12	L	373	0.97	5	Pms	Short-run and long-run elasticity of nonseasonal (Nov.-April) demand in 13 utilities in Washington.D.C.
		-0.70	0.28	--	1.55	138	--	1429	12	L	373	0.97	5	Pms	
		-0.10 (.20)	0.28	--	1.55	95	--	409	12	L	376	0.45	6	Pms	Short-run and long-run elasticities of seasonal (May-October use less non-seasonal use) demand
		-0.11 (.20)	0.28	--	1.55	95	--	409	12	L	376	0.45	6	Pms	
13.	Hansen-81	-0.47	--	--	--	--	--	--	14	DL	14 x12	0.97	5	Pau	Average monthly per connection municipal use in Salt Lake City, Utah

weighted average of the sectoral responses. The weights, however, are unknown and vary significantly from one community to another (because of varying proportions of residential, commercial, etc., water use). Price elasticity estimates for municipal water use, therefore, are expected to display greater variation than comparable estimates for sectoral use.

In attempting to characterize available estimates, many of the municipal studies can be discounted for one or more reasons. Metcalf (1926), Seidel and Baumann (1967), and Bain et al. (1966), failed to consider any explanatory variables other than price. Because of the possibility of collinearity between price and one or more excluded variables, the regression coefficients obtained for price in these studies may not be accurate estimates of the price effect.

Most early studies did not report standard errors or the results of significance tests on the regression coefficients (Metcalf 1926; Seidel and Baumann 1957; Renshaw 1958; Gottlieb 1963; Flack 1965). These elasticity estimates must also be discounted, as nothing is known of their significance. Also, there are cases where authors state that their results are not significant (e.g., Wong's (1972) result for Chicago suburbs having 5,000 population or less).

Finally, all but two of the studies utilized some measure of average price as the explanatory variable. Because of the complexity of water utility rate schedules and, perhaps, the time lags inherent in the billing process, it is not clear that average price is inferior to marginal price as an estimator of customer perception of price, economic theory notwithstanding. Average price has the benefit of capturing at least some of the effect on discretionary income of nonprice change in the rate structure. Still, most analysts favor marginal price.

Also, in the case of declining-block rates, where price is itself negatively correlated to quantity demanded, the estimated elasticity is likely to be more elastic than the true price response. (Increasing-block rates would produce an estimate less elastic than actual.)

Excluding studies which examine only price as an explanatory variable and those which do not report significance or those reported as insignificant by the author, and considering only studies using average price, the estimates of the price elasticity of municipal water demand include:

AVERAGE PRICE STUDIES

Cross-Sectional Data	
Gardner and Schick (1964)	-0.77
Wong (1972)	-0.53 -0.82 -0.46

Time-Series or Pooled Data	
Young (1973)	-0.65
	-0.60
Wong (1972)	-0.28
Sewell and Roueche (1974)	-0.39
	-0.46
Morgan and Smolen (1976)	-0.44
(winter period)	-0.45
(summer period)	-0.43
Hansen and Narayanan (1981)	-0.47

Results for the cross-sectional studies can be seen to fall in the range -0.46 to -0.82; the extremes pertain to groups of suburban communities in the Chicago area. These results apparently correspond to long-run elasticities. The time-series and pooled data studies listed here, on the other hand, made no attempt to distinguish between long-run and short-run response (no dynamic models estimated). If it is assumed that the results are biased in the direction of estimating the short-run response, then the generally more inelastic results (range: -0.28 to -0.65) seem plausible. Also, the Young study was later critized by Carver (1980) for improperly excluding seven years of data. Carver recalculated the elasticity at -0.20, a value more consistent with presumed short-run response.

Two of the municipal studies used marginal price as an explanatory variable; the results are summarized below:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Clark and Goddard (1977)	-0.63
	-0.60
Time-Series or Pooled Data--Long Run	
Carver and Boland (1980)	
Winter period	-0.70
Time-Series or Pooled Data--Short Run	
Carver and Boland (1980)	
Winter period	-0.05

These studies suggest that long-run elasticity for municipal demand is in the -0.60 to -0.70 range, and that short-run elasticity may be very small. The first result is fully consistent with the results of the studies of response to average price, while the second reveals greater inelasticity than observed by other investigators. It should be noted, however, that only one study of municipal demand specifically estimated short-run elasticity, and that result pertains only to winter period use. Carver and Boland also studied summer season water use but obtained insignificant results.

Residential Water Use

Studies of residential water use can be placed into two general categories: (1) those that address average annual or monthly uses, and (2) those that deal with seasonality by separating use into summer and winter periods or into seasonal and nonseasonal components. There are 27 studies in the first category, ranging from Fourt's (1958) unpublished analysis to a recent contribution by Jones and Morris (1984). The second group include six studies of winter (nonseasonal) use, five studies of seasonal (sprinkling) uses, and two studies of summer season use. All except one (Howe and Linaweaver 1967) of the studies in the second group are also in the first group, so that the total number of residential studies is 28.

Average Annual and Monthly Residential Use

Table V-2 summarizes studies of average annual and monthly residential water use. The 27 studies provide 60 individual estimates of price elasticity. In some cases, no test of the statistical significance of these estimates is provided, in others the estimate is stated by the author to be insignificant. Most studies in this group appear to have considered explanatory variables other than price.

In order to compare the results, those estimates stated (by the author) to be without statistical significance and those with no indication of a test for significance are excluded, as well as results of studies which apparently did not consider explanatory variables other than price. The elasticity estimates for studies based on average price follow:

AVERAGE PRICE STUDIES

Cross-Sectional Data	
Ware and North (1967)	-0.67
	-0.61
Turnovsky (1969)	-0.28
	-0.25

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES

No.	Study Code	Price Elasticity/ Significance	Price			Water Use			MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
			Min	Mean	Max	Min	Mean	Max							
1.	Fourt-58	-0.39	--	--	--	--	--	--	--	DL	34	0.68	3	Pms	34 urban systems from 1955 AWWA survey
2.	Conley-67	-1.02	--	--	--	--	--	--	9-15	DL	24	0.53	3	Pau	Residential per capita water use in 24 Southern California communities
		-1.09	--	--	--	--	--	--	9-15	DL	24	0.52	1	Pau	
3.	Hittman-70	-0.44	0	0.42	0.96	114	245	496	--	DL	27	0.59	3	Pms	27 cities from 1960 AWWA survey and mail questionnaire
4.	Grima-72	-0.93	--	0.45	--	--	143	--	7-9	DL	91	0.56	4	Pms	91 households in Toronto metro area
5.	Morgan-74	-0.49	--	--	--	--	--	--	11	L	31	0.93	8	Binary	Average elasticity for 35 households in Santa Barbara, CA
6.	Hogarty-75	-0.86	--	--	--	--	--	--	8	--	120 x9	--	--	Pmc	Short-run (3 months) and long-run (1 year) ave. elasticities for 120 households in Blacksburg, Virginia
		-0.56	--	--	--	--	--	--	8	--	120 x9	--	--	Pmc	
7.	Gardner-77	-0.24	0.15	0.85	1.95	39	79	228	7-9	L	75	0.28	4	Pms	75 cities in Minnesota from a mail survey
		-0.15	0.15	0.85	1.95	39	79	228	7-9	DL	75	0.36	3	Pms	
8.	Gibbs-78	-0.51	0	0.28	0.60	11	355	3733	2	LPL	1412	0.60	8	Pmc	Quarterly water use by 355 households in Miami, Fla. (four quarters)
9.	Camp-78	-0.24	0.45	0.93	0.165	115	197	326	13	L	288	0.60	13	Pms	288 residences in 10 Northern Mississippi cities
		-0.31	0.45	0.93	0.165	115	197	326	13	LPL	288	0.58	8	Pms	

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
10.	Danielson-79	-0.27	--	--	--	--	206	--	7	DL	261 x68	--	5	Pmc	261 households with 68 observations on each, Raleigh, North Carolina
11.	Cassuto-79	-0.30	--	--	--	--	--	--	9	L	246 x72	--	11	Pms	Monthly residential use in 246 census tracts for 72 months in Oakland, CA
		-0.21	--	--	--	--	--	--	9	L	246 x72	--	11	Pms	
12.	Billings-80	-0.49 (.25)	0.21	0.26	0.42	--	443	--	18	L	45	0.82	4	Pms,Dms	45 observations on average residential use in Tucson, Arizona (monthly billing periods)
		-0.27 (.10)	0.21	0.26	0.42	--	443	--	18	DL	45	0.83	4	Pms,Dms	
13.	Billings-82	-0.66	0.21	0.26	0.42	--	443	--	18	L	45	0.82	4	Pms,Dms	Reestimated from Billings-80 data with respecified P and D variables
		-0.56	0.21	0.26	0.42	--	443	--	18	DL	45	0.81	4	Pms,Dms	
14.	Agthe-80	-0.36 (.10)	0.21	0.26	0.42	--	443	--	18	L	45	0.83	5	Pms,Dms	Reestimated from Billings-80 data, interpreted as short-run elasticities
		-0.18 (.15)	0.21	0.26	0.42	--	443	--	18	DL	45	0.86	5	Pms,Dms	
		-0.50 (.10)	0.21	0.26	0.42	--	443	--	18	L	45	0.80	4	Pms,Dms	Estimates interpreted as long-run elasticities
		-0.27 (.10)	0.21	-.26	0.42	--	443	--	18	DL	45	0.81	4	Pms,Dms	
15.	Ben-Zvi-80	-0.73	--	0.79	--	--	344	--	12-16	DL	12	0.88	5	Pms	Non-industrial use per customer in 12 communities in Red River Basin

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
16.	Morris-80	-0.39	—	0.69	--	--	466	--	9-10	L	21	0.65	3	Pms	384 households in 21 Denver metro areas
		-0.16	—	0.63	--	--	424	--	9-10	L	384	0.37	11	Pmc	
17.	Jones-84	-0.07 not sig.	--	--	--	--	--	--	9-10	L	326	0.26	4	Pms,Dms	Reestimated from Morris-80 data (see above), elasticity does include D variable effects
		-0.18	--	--	--	--	--	--	9-10	LPL	326	0.28	4	Pms,Dms	
		-0.21	--	--	--	--	--	--	9-10	DL	326	0.25	4	Pms,Dms	
18.	Ware-67	-0.67	0.20	0.91	2.43	79	217	410	9	L	14	0.69	2	Pau	Annual use in 634 households in 14 Georgia communities
		-0.61	0.20	0.91	2.43	79	217	410	9	DL	14	0.68	2	Pau	
19.	Turnovsky-69	-0.28	--	--	--	--	--	--	9-11	L	14	0.86	3	Pau	"Planned" annual per capita non-industrial use in 19 Massachusetts towns
		-0.25	--	--	--	--	--	--	9-11	L	14	0.77	3	Pau	Elasticities for 1962 and 1965 cross-sections, respectively
20.	Primeaux-73	-0.26	—	0.86	--	--	75	--	11-14	L	402	0.56	11	Pau	402 households in 14 rural Northern Mississippi cities
		-0.37	—	0.86	--	—	75	--	11-14	L	402	0.47	4	Pau	
		-0.45	—	0.86	--	--	75	--	11-14	DL	402	0.52	4	Pau	

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
21.	Pope-75	-0.33 n.r.	--	--	--	--	--	--	6-11	--	1464	--	--	Pac	Arc elasticities for the first and the second year after price increase for 1464 households in 4 So. Carolina communities
		-0.14 n.r.	--	--	--	--	--	--	6-11	--	1464	--	--	Pac	
22.	Gibbs-78	-0.62	0.20	0.58	7.50	11	355	3733	2	LPL	1412	0.46	7	Pac	Quarterly use in 355 households in Miami, Florida
23.	Grunewald-78	-0.92	0.27	2.27	14.49	8	154	1429	9-11	DL	150	0.67	2	Pau	Annual residential use in 150 rural water districts in Kentucky
24.	Foster-79	-0.47	0.09	0.49	1.37	97	223	1020	--	LPL	218	0.54	4	Pau	Average annual use in 218 cities (1960 AWWA Survey)
		-0.52 -0.65	--	--	--	--	--	--	--	LPL	35	0.74	4	Pau	New England and North Atlantic region *(1960 & 1970 data*, respectively)
		-0.30 -0.33	--	--	--	--	--	--	--	LPL	97	0.74	4	Pau	Midwest
		-0.38 -0.60	--	--	--	--	--	--	--	LPL	42	0.74	4	Pau	South
		-0.58 -0.60	--	--	--	--	--	--	--	LPL	12	0.74	4	Pau	Plains and Rocky Mountains
		-0.36 -0.69	--	--	--	--	--	--	--	LPL	18	0.74	4	Pau	Southwest
		-0.[illegible]9 -0.68	--	--	--	--	--	--	--	LPL	14	0.74	4	Pau	Northern California and Pacific Northwest

TABLE V-2. RESIDENTIAL DEMAND--AVERAGE ANNUAL AND MONTHLY USES (Continued)

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
25.	Male-79	-0.20	0.22	0.73	4.86	36	271	838	5-9	L	56	0.50	4	Pau	Annual sales to metered residential customers in 56 utilities in 6 North Eastern states
		-0.37	0.22	0.73	4.86	36	271	838	5-9	LPL	56	0.69	4	Pau	
		-0.68	0.22	0.73	4.86	36	271	838	5-9	DL	56	0.73	4	Pau	
26.	Jones-84	-0.18	--	0.60	--	--	450	--	9-10	L	326	0.26	3	Pas	Reestimated from Morris-80 data using average price specification
		-0.29	--	0.60	--	--	450	--	9-10	LPL	326	0.23	3	Pas	
		-0.34	--	0.60	--	--	450	--	9-10	DL	326	0.23	3	Pas	
27.	Hanke-82	-0.15	--	--	--	--	--	--	--	L	16x4	0.26	6	Pmc	Sales to 69 single-family residences during 14 semi-annual periods in Malmo, Sweden

Primeaux and Hollman (1973)	-0.26
	-0.37
	-0.45
Grunewald et al. (1978)	-0.92
Foster and Beattie (1979)	-0.47
	-0.52
	-0.65
	-0.30
	-0.33
	-0.38
	-0.60
	-0.58
	-0.60
	-0.36
	-0.69
	-0.69
	-0.68
Male et al. (1979)	-0.20
	-0.37
	-0.68
Jones and Morris (1984)	-0.18
	-0.29
	-0.34
<u>Time-Series or Pooled Data</u>	
Gibbs (1978)	-0.62

These studies all employ some measure of average price as the estimator of the price variable, and all except the Gibbs (1978) study are based on cross-sectional data. Cross-sectional analyses are expected to yield estimates of price elasticity which approximate a long-run response. Pooled times-series/cross-sectional data bases, on the other hand, can support estimates of both long-run and short-run elasticity (provided a suitable dynamic model is used), as well as seasonal variation in price response. The single pooled data study utilizing average price (Gibbs 1978) did not attempt an estimate of short-run elasticity. All average price study results reported here, therefore, can be viewed as estimates of the long-run price elasticity of average annual water use.

The results of these studies range from -0.18 to -0.92. The most elastic estimate derives from the study by Grunewald et al. (1978) of 150 rural areas in Kentucky. The investigators in this case were unable to find significant relationships between water use and such variables as household size, housing value, and income; they obtained the elasticity from a bivariate regression (water use on average price). The possibility of a biased result seems substantial.

None of the studies in this group reported uniform commodity charges: all had either declining-block rates, mixed rate forms, or no information was provided. It can be hypothesized that, in the case of declining-block rates, elasticity estimates are biased (in the direction of greater elasticity). The degree of bias varies, however, with the rate designs' degree of deviation from uniform charges. The Jones and Morris study (1984), for example, is based on data from a region with both declining-block and increasing-block rates (Denver). It is not surprising, then, that the results are among the most inelastic estimates (ranging from -0.18 to -0.34, depending on the model specification).

These results are also in good agreement with those of Turnovsky (1969), Primeaux and Hollman (1973), and Male et al. (1979), excluding the double-log model. It seems likely that the unbiased elasticity of annual water use in the residential sector with respect to average price is in the vicinity of -0.20 to -0.40.

Residential water use studies which employ some measure of marginal price as an explanatory variable are as follows:

MARGINAL PRICE STUDIES

<u>Cross-Sectional Data</u>	
Fourt (1958)	-0.39
Hittman Associates (1970)	-0.44
Grima (1972)	-0.93
Gardner (1977)	-0.24 -0.15
Camp (1978)	-0.24 -0.31
Ben-Zvi (1980)	-0.73
Morris and Jones (1980)	-0.39 -0.16
Jones and Morris (1984)	-0.07 -0.18 -0.21
<u>Time-Series or Pooled Data</u>	
Gibbs (1978)	-0.51

Danielson (1979)	-0.27
Billings and Agthe (1980)	-0.49 -0.27
Agthe and Billings (1980)	
Short run	-0.18 to -0.36
Long run	-0.27 to -0.50
Billings (1982)	-0.66 -0.56
Hanke and de Mare (1982)	-0.15

Except for the Grima (1972) and Ben-Zvi (1980) studies, the cross-sectional results show quite inelastic demand for residential water, all falling within the range -0.07 to -0.44. The Ben-Zvi study is based on a small sample (data for 20 communities of widely varying size, each community comprising one observation) of users, all of whom face delining-block rate designs. Also, in spite of its characterization as a "residential" study, the text suggests that water use data may include commercial and institutional use (it may be "nonindustrial" rather than residential). These factors could explain the discrepancy between Ben-Zvi's results and those of similar studies performed elsewhere. On the other hand, there is no obvious explanation for the differences between Grima's results and those of other investigators, other than differing price response.

Of the six time-series or pooled data studies, five utilized static models, yielding estimates of long-run price elasticity (Agthe and Billings [1980] used a Koyck transform dynamic model). The static models provide estimates of long-run price elasticity in the range of -0.15 to -0.66. The long-run results from the Agthe and Billings dynamic model (-0.27 to -0.50) also fall within this range. The most elastic estimates are due to Billings (1982), who employed a marginal cost obtained from a regression equation (he regressed the total water bill on water use) rather than actual rate schedules. It is not known what type of bias, if any, this procedure might create.

Billings and Agthe (1980), Agthe and Billings (1980), and Billings (1982) all included a bill difference variable in their models and all obtained significant negative coefficients for this term. None of the reports indicate the relationship between the value of the bill difference term and marginal price; the elasticity calculations reported do not take such a relationship into account. Where bill difference is negatively correlated with marginal price (because of fixed charges or a declining-block rate form), proper calculation of elasticity with respect to marginal price will produce a more inelastic result than when the bill difference is ignored.

Based on these marginal price studies, the true long-run elasticity of annual residential water demand is apparently in the vicinity of the range -0.20 to -0.40, the same range deduced from the average price studies described above.

Agthe and Billings (1980) also provide estimates of short-run elasticity which are slightly more inelastic than the corresponding long-run estmates.

Winter (Nonseasonal) Residential Use

Table V-3 lists information describing studies of residential winter season water use. Five of these studies report significant price elasticities; all five utilize marginal price as the price variable. The elasticities are:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Howe and Linaweaver (1967)	-0.23
Grima (1972)	-0.75
Ben-Zvi (1980)	-0.79
Howe (1982)	-0.06
Time-Series and Pooled Data	
Danielson (1979)	-0.30

Once again, the Grima and Ben-Zvi studies produce much more elastic estimates than obtained elsewhere. Possible biases in the Ben-Zvi estimate are as described above; no biases have been identified for the Grima study. The Danielson estimate is obtained from a static model and refers, therefore, to the long-run response. It is consistent with the Howe and Linaweaver result.

The Howe and Linaweaver (1967) results have been long regarded as the most reliable available estimates of residential price elasticity. Their study used primary data obtained from a carefully designed national sample, and the data analysis was comprehensive and thoroughly documented. Howe (1982) reanalyzed this data set, adding a bill difference variable to the explanatory factors previously considered. The dependence of the bill difference on marginal price was accounted for in calculating price elasticity, giving an estimate substantially more inelastic than previously available. All available evidence points to Howe's result as the most reliable estimate of residential winter (nonseasonal) price elasticity.

Gallagher and Robinson (1977) report results of a pricing experiment in Australia which are consistent with the empirical results shown here. They estimate winter residential price elasticity at -0.24, based on hypothetical prices, using no bill difference term.

TABLE V-3. RESIDENTIAL DEMAND--DOMESTIC USE (WINTER, NONSEASONAL, IN-HOUSE)

No.	Study Code	Price Elasticity/ Significance	Price			Water Use			MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
			Min	Mean	Max	Min	Mean	Max							
1.	Howe-67	-0.23	--	0.40	--	--	226	--	11	DL	21	0.72	2	Pms	21 residential areas (East and West)
2.	Howe-82	-0.06	--	0.40	--	--	261	--	11	L	21	--	3	Pms,Dms	Reestimated from Howe-67 data with D-variable, elasticity includes D-effects
3.	Morris-80'	-0.09 not sig.	--	0.62	--	--	221	--	9-10	L	21	0.66	3	Pms	Average data for individual households in 21 Denver metro areas
4.	Danielson-79	-0.30	--	--	--	--	219	--	7	DL	--	--	5	Pms	Average use during Nov.-April (261 households in Raleigh, N. Carolina)
5.	Ben-Zvi-80	-0.79	--	0.79	--	--	308	--	12-16	DL	20	0.81	3	Pms	Lowest monthly non-industrial use in 20 communities in Red River Basin
6.	Grima-72	-0.75	--	0.45	--	--	128	--	7-9	DL	91	0.49	4	Pmc	Average winter use during Nov.-March for 91 households in Toronto area

Summer Residential Use

Table V-4 shows studies of summer and seasonal residential water use. Two of these contain significant estimates of the price elasticity of summer residential water use; both are cross-sectional and based on marginal price:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Grima (1972)	-1.07
Howe (1982) Eastern U.S. only	-0.57

The Howe study uses the data set from the 1967 Howe and Linaweaver study, and incorporates a bill difference variable. The relationship between marginal price and the bill difference variable is accounted for in calculating price elasticity. The result is considered more representative than Grima's earlier estimate, which is based on a simpler price specification. Howe attempted a similar calculation for communities in the western U.S., but the result (-0.43) was not significant.

Seasonal (Sprinkling) Residential Use

Four studies shown in table V-4 consider seasonal use, defined as the excess of annual use over the nonseasonal component (estimated from winter use). Following Howe and Linaweaver's (1967) definition, seasonal use is assumed to consist primarily of water used for weather-related purposes, such as irrigating lawns and gardens. All available studies used marginal price as the price variable:

MARGINAL PRICE STUDIES

Cross-Sectional Data	
Howe and Linaweaver (1967)	
Eastern U.S.	-1.57
Western U.S.	-0.73
Ben-Zvi (1980)	-0.82

TABLE V-4. RESIDENTIAL DEMAND--SEASONAL (SPRINKLING) AND SUMMER USES

No.	Study Code	Price Elasticity/ Significance	Price Min	Price Mean	Price Max	Water Use Min	Water Use Mean	Water Use Max	MD inches	f(X)	N	R^2	No. of Var.	Price Spec.	Remarks
1.	Howe-67	-1.57	0.17	0.40	1.02	37	226	481	10	DL	11	0.93	3	Pms	Average day sprinkling demand in 11 eastern areas (Des Moines, Fort Worth, Little Rock, Washington, D.C., Baltimore, Philadelphia)
		-0.73	0.24	0.36	0.61	167	387	780	12	DL	10	0.67	2	Pms	Average day sprinkling in 10 western areas (Oakland, Los Angeles, San Diego)
2.	Grima-72	-1.07	--	0.45	--	--	158	--	7-9	DL	91	0.55	4	Pms	Summer use (May-August) in 91 households in Toronto metro area
3.	Danielson-79	-1.38	--	--	--	--	27	--	7	DL	--	--	4	Pms	Sprinkling use (May-Oct. use less Nov.-April use) in 267 households in Raleigh, North Carolina
4.	Ben-Zvi-80	-0.82	--	0.79	--	--	141	--	12-16	DL	12	0.38	4	Pms	Sprinkling use (Ave. use in June-Sept., less domestic use, in 12 towns in Red River Basin)
5.	Morris-80	-0.73	--	1.13	--	--	240	--	9-10	L	21	0.64	3	Pms	Sprinkling use per household (ave. use in March-October, less domestic) in 889 houses in 21 districts in Denver metro area
6.	Howe-82	-0.57	--	0.41	--	--	415	--	10	L	11	--	4	Pms,Dms	Summer use (domestic & sprinkling) in 11 eastern areas
		-0.43 not sig.	--	0.36	--	--	658	--	12	L	10	0.84	4	Pms,Dms	Summer use in 10 western areas (reestimated from Howe-67 data)
7.	Morgan-76	-0.55	--	--	--	--	--	--	10-17	L	165	0.54	4	Pau	Sprinkling demand (dry period usage minus minimum wet period usage)

Morris and Jones (1980)	-0.73
<u>Time-Series and Pooled Data</u>	
Danielson (1979)	-1.38

Since the Ben-Zvi and Morris and Jones studies used data from the western U.S. (Southwest and Denver, respectively), they are consistent with Howe and Linaweaver's estimate for elasticity in that region. Similarly, Danielson, who used data from North Carolina, provides an estimate which is consistent with Howe and Linaweaver's result for the eastern U.S. None of these studies used a bill difference variable (bill difference cannot be calculated for a component of water use). Based on experience with application of bill difference variables to summer season use, it seems likely that the results shown are biased upward (too elastic).

Industrial Water Use

Table V-5 describes, in summary form, nine studies of industrial water use. While all of these studies attempted to include some type of price variable, not all provided useful estimates of price elasticity. In particular, DeRooy (1974), Ben-Zvi (1980), and Zeigler and Bell (1984) analyzed self-supplied industrial water use and used the average cost (or, in the case of Zeigler and Bell, both average and marginal cost) of water to the firm as the price variable. "Price"-quantity observations, expected to be points on the demand curve for water, are more likely, in this case, to be points on the supply curve. Also, Rees (1969) estimated some models containing a term described as "price paid for all purchased supplies"; other models contain a measure of the price of metered water. It is not clear whether the former term is a measure of price or cost.

Because of the price-cost problem, only those studies which address the use of municipally-supplied water yield useful estimates of price elasticity. Six of the studies contain such results, as listed below. In most cases, it is not possible to determine whether average or marginal price was used.

MARGINAL AND/OR AVERAGE PRICE STUDIES

Cross-Sectional Data	
Rees (1969)	
Chemical firms	-0.96
Food firms	-3.29 to -6.71
Beverage firms	-1.30 to -4.10
Nonmetallic mineral firms	-2.50

TABLE V-5. INDUSTRIAL DEMAND FOR WATER—EMPIRICAL STUDIES

No.	Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
1.	Rees-69	Aggregate industrial	+0.81 n.r.	--	DL	166	0.35	E,t,P_p	253 manufacturers in S.E. England
		Chemical firms	- 0.96 n.r.	--	DL	50	0.37	Pr,Qs	E = employment; T = tonnage of raw materials used by the firm
		Food firms	--	-3.29 to -6.71	LPL	15	0.60	Pr	
		Drink firms	--	-1.30 to -4.10	LPL	8	0.36	Pr	P_p = price paid for all purchased water
		Paper and paper products	-1.95 n.r.	-1.44 to -2.88	DL	22	0.55	Pp, Qs	Pr = price paid for metered purchases
		Plastic and rubber	not significant e.g. (positive price coeff.)						
		Non-metallic mineral firms	-2.50 n.r.	--	L	13	0.31	Pr	Q_s = self-supplied water
2.	Ethridge-70	Poultry processing firms	-0.43 (for Pmt+Pss); -0.63 (for P_{wts})		LPL	26	0.55	Pmt+0.5 Pss and P_{wts}	27 obs. on 5 poultry proc plants; Pmt = sewer surcharge on BOD_5; Pss = sewer surcharge on SS; P_{wts} = marginal price paid for sewer and water

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES (Continued)

No.	Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
3.	Turnovsky-69	Aggregate industrial purchases from municipalities	-0.50	-0.47 to -0.84	L	16	0.92	Pau, S^2	Industrial sales in 19 Massachusetts towns
			-0.63		L	18	0.89		Pau = average price
									S^2 = supply variance
4.	Ridge-72	Brewery--SIC 2082	-0.30		L	12	0.64	Pmc, X_1	90 plants in 4 SIC categories
		Fluid Milk-SIC 2026	-0.60		L	10	0.84	Pmc, X_1,E	Pmc = marginal price
		Poultry Process.--SIC 2015	-0.80 not sig.		L	10	0.59	Pmc,X_1,E	X_1 = plant size
									E = employment
5.	Elliot-72	Aggregate industrial purchases (in gpd per $1000 value added in manufacturing)	-0.70 (for Pms)						198 obs. for 34 cities in the U.S.
			-0.61 (for surcharge)		L	183	0.32	Pms, S,L_p and V	Pms = marginal price
									S = sewer surcharge
									Lp = price of labor
									V = % value added by SIC 20

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES (Continued)

No.	Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
6.	DeRooy-74	Cooling water	-0.89 (for unit cost)		LPL	28	0.81	X_t, P_u, T	30 chemical plants in northern New Jersey
		Processing water	-0.36 (for unit cost)		LPL	23	--	X_t, P_u, T	X_t = value of output
		Steam generation water	-0.48 (for unit cost)		LPL	24	--	X_t, P_u, T	P_u = total unit cost of water
		Sanitation water	Not significant		L	18	0.92	E	T = technol. index
									E = employment
7.	Grebstein-79	Aggregate industrial		-0.33 to -0.80				K,L,W	All SIC 2-digit industries in the U.S.
									K = capital L = labor W = water input
8.	Ben-Zvi-80	Food industry--SIC 20	-2.42		DL	24	0.84	P_w, X	84 industrial plants in Red River Basin
		Lumber--SIC 24	-0.56 not sig.		DL	6	0.98	P_w, X	
		Paper--SIC 26	-0.56		DL	14	0.66	P_w, X	P_w = ave. purchase price plus treatment cost
		Chemicals--SIC 28	-1.47		DL	18	0.69	P_w, X	X = annual sales of the plant
		Petroleum--SIC 29	-0.15		DL	12	0.95	P_w, X	
		Stone and Clay	-1.13		DL	10	0.92	P_w, X	

TABLE V-5. INDUSTRIAL DEMAND FOR WATER--EMPIRICAL STUDIES (Continued)

No. Study Code	Industry or Purpose of usage	Price Elasticity/Significance	Range of Price Elasticities	f(X)	N	R^2	Variables in the Equation	Remarks
9. Ziegler-84	Self-supplied water	-0.98		LPL	23	0.76	Pac, X_1, and X_2	23 high-volume water using paper and chemical plants Pac = average unit cost of water X_1,S_2 = dummy variables

Turnovsky (1969)	
Aggregate industrial, 1962 data	-0.51
Aggregate industrial, 1965 data	-0.63
Elliot and Seagraves (1972)	
Aggregate industrial	-0.60
Ridge (1972)	
Breweries (SIC 2082)	-0.30
Fluid milk producers (SIC 2026)	-0.60
Poultry processing (SIC 2015)	-0.80
Grebstein and Field (1979)	
Aggregate industrial	-0.80
Time-Series and Pooled Data	
Ethridge (1970)	
Poultry processing	-0.63

None of the studies included here experimented with the price specification, or considered bill difference variables. The Ethridge study used pooled data but did not employ a dynamic model. The elasticity estimate, therefore, applies to the long-run, and is comparable to the similar estimate of Ridge (-0.63 vs. -0.80). The Rees results, obtained for Southeast England, are notable for the high level of elasticity found. This may be the result of collinearity between price and other omitted variables (the models used only price and total water intake to explain municipal water withdrawal).

It appears, on the basis of this evidence, that industrial water demand is, in general, more elastic than residential demand and varies markedly from one industrial sector to another. The best available estimates of the elasticity of aggregate industrial water demand (the municipally supplied fraction only) are in the range -0.50 to -0.80.

Commercial Water Use

As shown on table V-6, only one study has attempted to estimate the price elasticity of commercial water use (Lynn et al. 1978). This study, which developed six separate models (for five categories of use in the Miami, Florida, area), resulted in significant estimates of price elasticity in four cases, as follows:

TABLE V-6. COMMERCIAL DEMAND FOR WATER--EMPIRICAL STUDIES

No.	Study Code	Type of Establishment	Price Elasticity/Significance	f(X)	N	R^2	Variables in equation	Remarks
1.	Lynne-78	Department Stores	-1.33	LPL	20	0.78	Pms, X_1, X_2	Pms = marginal price for average user in sample
								X_1 = store area
		Grogery and Supermarket	-0.76	LPL	19	0.73	Pms, S_1, D_1	X_2 = area of restaurant D_1 = dummy variable for presence of kitchen
		Motels and Hotels	-0.24	LPL	40	0.95	Pms, NR, P_2,DB	NR = number of rooms for rent
			-0.12	LPL	93	0.94	Pms,NR, P_2	P_2 = weighted average of maximum
								BH = Prices for rooms
		Eating and Drinking	-0.174 (0.20)	LPL	24	0.25	Pms, DH, BH	DB = dining room plus bar area
		Other commercial	-0.48 (0.20)	LPL	32	0.35	Pms, X_1, X_3, D_2	DH = dining room area BH = bar room area D_2 = dummy variable for presence of water cooled air conditioning

Cross-Sectional Data

Lynn et al., (1978)	
Department stores	-1.33
Groceries and supermarkets	-0.76
Hotels, motels (primary data)	-0.24
(secondary data)	-0.12

No experimentation with the price variable specification is evident, and no bill difference variable was considered. The results also include an estimate of elasticity for the "other commercial" category, found to be -0.48 but only significant at the 0.20 level. Taken together, these estimates suggest that the commercial sector may be more elastic than the residential sector, but that elasticity may vary substantially from one category of user to another.

CRITIQUE

Explanatory Variables

One of the most important opportunities for bias in price elasticity studies (after sample selection and data measurement) lies in the choice of the explanatory variables to be considered in the regression model. Price is commonly collinear with other variables, and the omission of those variables may bias the price coefficient.

For example, price is usually lower in larger communities, which also contain relatively greater numbers of multi-unit residential buildings. If the dependent variable is per capita water use, it would be expected to be higher if a larger fraction of the population live in smaller household units, and it would also be higher if the price were lower. Omission of explanatory variables which describe household size or fraction multi-unit housing would result in both effects being reflected in the price coefficient, leading to an overestimate of the price elasticity.

Another example can be proposed which is relevant to time-series data sets. If real price has fallen over time (as it has in most locations prior to the late 1970s), but affluence has risen, both trends would be expected to reduce water use. The omission of any satisfactory proxy for affluence would again, force the price coefficient to reflect the combined effect, overestimating price elasticity.

One variable omitted by all but the most recent studies is the bill difference term, also known as a Nordin variable. This factor captures some of the income effect associated with various rate structures. Customers served under decreasing-block rate structures will face positive bill differences. If those same customers are compared to others who pay a lower marginal price under an unblocked structure (without a minimum or service charge), the decreasing-block customers will be seen to use less water for two reasons: (1) they face a higher marginal price; and (2) they also pay large inframarginal charges, reducing discretionary income. Omitting the bill difference variable from the regression would cause the price coefficient to reflect both effects, overestimating price elasticity.

Review of the studies analyzed in this report indicates that most models are very sparsely specified, that is, many relevant variables are omitted. Where the omitted variables are correlated with water use and collinear with price, or when they include a bill difference term (and block-type rate structures are in use), bias in the price coefficient is likely to result. In many plausible cases, such as those described above, the direction of the bias is upward: the estimate is more elastic than if the model were correctly specified.

Price Variable Specification

Another common source of bias concerns the specification of the price variable. Most early studies measured price as the average revenue contributed by all utility customers (average price). Later, efforts were made to measure average revenue contributed by those users included in the data sample, or to measure the marginal price faced by those users. In the case of block-type rate schedules, marginal price sometimes represents the price faced at the margin by the "average" user, sometimes it is the average of all marginal prices in effect throughout the sample, and sometimes it is the incremental price for a block of usage in a "typical" range.

Economists have long recognized both average and marginal price specifications, taken by themselves, to be inadequate. While rational users can be presumed to base their usage decisions on marginal price, it is not clear that the information typically available facilitates this behavior. Furthermore, complex utility rate schedules include income transfers which may affect use, and which are not captured by conventional income variable specifications.

The bill difference variable, described in chapter III, when combined with a marginal price variable, incorporates at least some of the complexity of utility rate schedules. Bill difference was first introduced to residential water use studies by Billings and Agthe in 1980, and most residential studies published since then have incorporated it. However, only one study (Howe 1982) explicitly calculates price elasticity as a function of both marginal price and bill difference coefficients. The bill difference variable has not, as yet, been applied to studies of nonresidential water use.

Level of Aggregation

There are few truly homogeneous groups of water users. Most user classes or categories are comprised of a number of very different water users, each using water in a number of very different ways. Still, systematic differences in price response can be observed among user classes. When price response is measured at too high a level of aggregation, these differences are submerged in the data, and the result is an elasticity which is, at best, a weighted average of the component elasticities.

Regression theory requires that the variance in the dependent variable be unrelated to the values of the explanatory variables (the "constant variance" or "homoscedasticity" assumption). It is unlikely that this assumption is met when the explanatory variables include weather terms: since some water uses are weather dependent, the variance of water use almost certainly changes with the weather. Data aggregated over time are, therefore, likely to violate the assumption (to be heteroscedastic); the longer the time and the greater the changes in weather, the greater the range of variance. Heteroscedasticity can be minimized, but not eliminated, by analyzing seasonal, rather than annual water use.

The best example of an aggregation problem is the practice of analyzing average annual municipal water use. Neglecting statistical problems arising from heteroscedasticity, the elasticity which results is a weighted average of residential, commercial, institutional, industrial, etc., elasticities, as well as a weighted average of summer and winter elasticities for each of the classes. As the weights vary from community to community (because of different proportions of users in each class or because of different weather patterns), the aggregate elasticity varies as well. Such results may be useful in the community for which they are derived, but they are not usually transferable to other communities.

Since studies have shown relatively large differences between elasticities for residential winter use and residential summer use, the practice of analyzing average residential use without regard to season conceals the true components of price response. The same may be true for other sectors of water use, but no studies are yet available which conclusively demonstrate significant seasonal differences.

The most generally applicable estimates of price elasticity, therefore, are those which apply to the smallest and most homogeneous classes of water use. In the case of residential use, these would include estimates of winter (nonseasonal) and summer (or, alternatively, seasonal) elasticities. In the case of industrial or commercial water use, estimates of elasticity for specific categories (e.g., poultry processing, department stores, etc.) are preferable to estimates for the class as a whole. Using higher levels of aggregation introduces study area-specific variation into the estimates, producing a broader range of results while making application to other areas more difficult.

Long-Run vs. Short-Run

Economic theory predicts that goods, such as water, which are complementary to capital investment and which involve use habits, show a response to price which varies according to how many of the complementary goods or habits can be adjusted. Since most such adjustments can occur only with the passage of time, the price response is expected to grow over time (as the full adjustment to price change is phased in). In the case of water, this may be complicated by uncertainty over behavior in the first few billing cycles after a price change ("announcement effect," etc.). Still, short-run (corresponding to short-term, with time scale on the order of months up to one year) response is expected to be more inelastic than long-run (long-term with time scale on the order of several years or more) reactions.

Only a few studies report comparable data for short-run and long-run elasticities. All of these find the short-run response more inelastic than long-run demand, as predicted. One study (Carver and Boland 1980) found short-run response to be nearly zero (elasticity = -0.05), while Agthe and Billings (1980) recorded a relatively small movement in the direction of inelasticity (a range of -0.18 to -0.36 for the short-run, compared to -0.27 to -0.50 for the long-run).

Few investigators have employed the time-series data and dynamic models necessary to develop short-run and long-run estimates from the same data set. No studies of short-run vs. long-run elasticities have been performed for the nonresidential sectors. While not critically important for long-range forecasting or demand modeling generally, short-run elasticity estimates are very useful in rate design and revenue forecasting activities. Short-run estimates may also be relevant to drought management planning, where the short-term response to emergency price changes is of interest.

Nonresidential Water Use

Very little effort has been devoted to estimating price elasticity for nonresidential user classes. In spite of the considerable importance of commercial and industrial water use in many systems, little is known of the response of these users to changes in price.

In the industrial area, attention has been given to a few specific categories by a few investigators. The results, which show great variability among categories, demonstrate that much more must be done before any real understanding of price response in this sector can be developed.

The commercial sector has been almost entirely ignored. A single study was found, which develops elasticity estimates for a few categories. Most commercial and institutional use does not fall into these categories, and its price response is still unknown.

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APPENDIX

Annotated Bibliography
Description of Data Bases by Abstract Number
Author Index

1 **Agthe, Donald E., and R. Bruce Billings. 1980.**
Dynamic Models of Residential Water Demand.
Water Resources Research 16(3):476-80.

Abstract:
In this article static, Fisher-Kaysen, Koyck, flow adjustment, and stock adjustment econometric models of the demand for residential water are tested for their ability to explain the monthly residential demand for water in Tucson, Arizona. Monthly data for the period January 1974-September 1977 were used to test the models. The variables that are included are monthly water consumption of the average household in 100 cubic feet (Q); marginal price of the average household in cents per 1000 cubic feet (P_{ms}); a bill difference variable (D_{as}); income per household in dollars per month (I); and evapotranspiration for Bermuda grass minus rainfall in inches (X). The difference variable (D_{as}) is included in the models because the Tucson water rates include both increasing-block and flat rate charges. The D_{as} variable will measure the income effect of alterations in the flat rate or service charge. The price, difference, and income variables are adjusted by the consumer price index to establish real rather than nominal values.

The demand models are presented in both linear and logarithmic forms. The models that were found to be more highly significant and applicable are the static and dynamic Koyck models. The two models are presented as:

(1) Static

(a) Linear

$$Q = \underset{(-0.94)}{-15.2} - \underset{(-3.09)^*}{0.327 P_{ms}} - \underset{(-4.25)^*}{2.00\, D_{as}} + \underset{(2.41)^*}{0.0480\, I} + \underset{(10.22)^*}{0.0146\, X}$$

R^2 adj. = 0.801 F = 45.3 Df = N.R.

(b) Double-log

$$\text{Log } Q = \underset{(-1.36)^*}{\text{Log } -8.07} - \underset{(-1.56)^*}{0.264 \text{ Log } P_{ms}} \underset{(-5.07)^*}{-0.124 \text{ Log } D_{as}} + \underset{(1.89)^*}{1.70 \text{ Log } I}$$

$$+ \underset{(9.33)^*}{0.0893 \text{ Log } X}$$

R^2 adj. = 0.814 F = 48.0 Df = N.R.

(2) Koyck dynamic model

(a) Linear

$$Q = \underset{(-1.06)^*}{-16.1} - \underset{(-2.31)^*}{0.241\, P_{ms}} - \underset{(-3.37)^*}{1.58\, D_{as}} + \underset{(2.21)^*}{0.0415\, I} + \underset{(6.34)^*}{0.0114\, X}$$

$$+ \underset{(2.58)^*}{0.252\, Q_{t-1}}$$

R^2 = 0.830 F = 42.9 d.f. = N.R.

(b) Log

$$\underset{(-1.33)^*}{\text{Log}Q = \text{Log} -6.73} \underset{(-1.22)}{-\ 0.179} \text{ Log } P_{ms} \underset{(-3.78)^*}{-\ 0.0866} \text{ Log Das } \underset{(1.73)^*}{+\ 1.33} \text{ Log I}$$

$$\underset{(6.66)^*}{+\ 0.066} \text{ Log X } \underset{(3.94)^*}{+\ 0.326} \text{ Log } Q_{t-1}$$

R^2 adj. = 0.864 F = 55.8 Df = N.R.

The values in parentheses are t-statistics, and the * indicate significance at the 0.10 level or better. The variable Q_{t-1} is included to account for adjustments from the previous time period. None of the models demonstrated significant autocorrelation (Durbin-Watson test). The P_{ms} variable in the Koyck logarithmic model was significant at the 0.15 level.

In the Koyck model the short-run price elasticities are -0.358 and -0.179, linear and log forms, respectively. Elasticities of the linear models are calculated at the means. For both the Koyck and static models the long-run price elasticities range from -0.266 to -0.486. Again for both models, the long-run difference elasticities range from -0.124 to -0.149. The authors do not present a price elasticity result which accounts for the effect of price on the bill difference term.

Data Base Information:

Study Area Data

Location and water users: residential water users in Tucson, Arizona.
Mean summer temperature: 85 degrees F.
Mean summer precipitation: 5 inches.
Mean summer evapotranspiration: 21 inches.
Mean summer moisture deficit: 18 inches.
Water rates: increasing block rates and flat rates.
User sector: all residential (all single family apartments, condominiums, mobile homes, duplexes, and triplexes served with individual water connections).
Area character: urban.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: secondary data from City of Tuscon, Arizona Department of Economic security, and U.S. Weather Bureau.
Measurement period: January 1974-September 1977.
Dependent variable: monthly water consumption per household.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: not specified.
Price variable specification: (1) marginal price of average user in sample, (2) Nordin's bill difference for average user.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: short run: -0.179 to -0.358, long run: -0.266 to -0.497.

Bill difference elasticities: long run: -0.124 to -0.144. No estimate is provided of total price elasticity, considering both price and effect of price on bill difference.

2 Bain, Joe S., Richard E. Caves, and Julius Margolis. 1966. Northern California's Water Industry. Johns Hopkins University Press. Baltimore, Maryland.

Abstract:

From a cross-section of 41 California cities in 1955, the authors analyzed the price elasticity of urban water, using aggregate municipal data. The sample was spatially biased in that Southern California was overrepresented and the Central Valley underrepresented. This was due to the Central Valley cities being served by private utilities or utilizing flat rates, both being excluded from the sample. Furthermore, there was high negative correlation between price and average temperature because of lower pricing policies in Southern California. Therefore, a multiple regression analysis would have overestimated price elasticity. A simple regression analysis was performed using logarithms of annual quantity per capita as the dependent variable and the logarithms of average price as the independent variable. The analysis estimated a statistically significant price elasticity of -1.099. The value is suspect because of the data problems noted. No coefficients or statistical tests were reported.

Data Base Information:

Study Area Data

Location and water users: sampled 41 waterworks systems in California.
Mean summer temperature: 65-75 degrees F.
Mean summer precipitation: 0-2 inches.
Mean summer evapotranspiration: 9-15 inches.
Mean summer moisture deficit: 7.8-15 inches.
Water rates: varied rates in multi-site data, however, no cities that used flat rates were included in the sample.
User sector: aggregate municipal.
Area character: urban.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: secondary data from waterworks systems.
Measurement period: 1955-56 fiscal year.
Dependent variable: average annual water use per capita (gallons).
Estimating technique: regression analysis.
Price variable specification: average price for all customers of utility.

Minimum, maximum, and mean variable values:

P = $1.30-$3.60 per 1,000 cubic feet in 1955 (no mean value reported).
P = $1.30-$5.20 (1,000 cubic feet in 1960 (no mean value reported).
Q = 14,000-154,000 gallons in 1955-56 fiscal year (no mean).

Price elasticity: -1.099 (average price).

3 Ben-Zvi, Samuel. 1980. Estimates of Price and Income Elasticities of Demand for Water in Residential Use in the Red River Basin. U.S. Corps of Engineers. Tulsa, Oklahoma.

Abstract:

This report describes a cross-sectional comparison of nonindustrial (i.e., residential) water use in 20 communities located in the Red River Basin extending from northwest Louisiana to northwest Texas. In-house, sprinkling, and annual average water use models are estimated separately for three subregions of the area.

The estimated equations for the three types of water use in the eastern subregion are:

(1) In-house

$$\log Q_{ih} = \underset{(-1.26)}{-4.16} + \underset{(2.58)^*}{1.09} \ln I - \underset{(-3.32)^*}{0.794} \ln P_{ms} + \underset{(1.62)}{0.62} \ln H$$

$R^2 = 0.81$ F = 22.4 d.f. = 3,16 N = 20

(2) Sprinkling

$$\ln Q_s = \underset{(-0.19)}{-13.1} + \underset{(0.98)}{1.80} \ln I \underset{(-2.13)^*}{-0.821} \ln P_{ms} + \underset{(0.25)}{0.44} \ln I_s \underset{(-0.13)}{-0.27} \ln F_s$$

$R^2 = 0.38$ F = 3.69 d.f. = 4,7 N = 12

(3) Annual average

$$\ln Q_a = \underset{(-6.19)^*}{-1.07} + \underset{(1.25)}{0.64} \ln I - \underset{(-2.57)^*}{0.734} \ln P_{ms} + \underset{(1.68)}{0.78} \ln H + \underset{(1.65)}{0.07} \ln T$$

$$- \underset{(-0.23)}{0.11} \ln F_s$$

$R^2 = 0.88$ F = 8.56 d.f. = 5,6 N = 12

Where: Q_{ih} = daily in-house water use per nonindustrial customer in each community in gallons calculated by dividing the lowest monthly total nonindustrial water sales by the number of residential units in the community; Q_s = sprinkling demand obtained by subtracting average daily winter use from average daily summer use in gallons per day per connection; Q_a = average annual water use in gallons per day per connection. The independent variables are: I = per capita income; P_{ms} = marginal price for each community; H = number of residents per dwelling unit; T_s = average summer temperature (June, July, August, September) in degrees F; and, F_s = total summer precipitation for the four-month period in inches. The numbers in parantheses show t-values, while asterisks indicate coefficients significant at the 0.05 probability level, or better.

Price elasticity coefficients for the above models are: -0.794, -0.821, and -0.734; all statistically significant at the 0.05 level. The regression coefficients and their significance are similar in the models estimated for samples from central and western regions of the study area, with price and income elasticities being consistently the lowest for each type of water use in the western subregion.

Data Base Information:

Study Area Data

Location and water users: 58 communities in Red River Basin (Northwest Louisiana to Northwest Texas).
Mean summer temperature: 76.5 degrees F.
Mean summer precipitation: 1-14 inches.
Mean summer evapotranspiration: 17-20 inches.
Mean summer moisture deficit: 11-17 inches.
Water rates: water rates vary among communities, but prevailing tariff is decreasing block with minimum service charge and minimum allowance.
User sector: residential (nonindustrial).
Area character: urban.

Water Use Data

Maximum number of cases: 20 observations in one equation.
Type of measurement: secondary; data provided by U.S. Army District.
Measurement period: 1978.
Dependent variable: daily in-house water use per nonindustrial customer (gallons); sprinkling demand in gallons per day per connection; average annual water use in gallons per day per connection.
Summer season definition: June, July, August, September.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: marginal price for each community.

Minimum, maximum, and mean variable values:

Q_{ih} = mean: 308 gallons/day/connection.
Q_s = mean: 141 gallons/day/connection.
Q_a = mean: 344 gallons/day/connection.
P_{ms} = mean: $0.79/1000 gallons.
H = mean: 2.80 persons/household.
T_s = mean: 76.5 degrees F.
F_s = mean : 17.7 inches.

Price elasticities: -0.794, -0.821, -0.73 for in-house use, sprinkling demand, and average annual use, respectively.

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4 Ben-Zvi, S. 1980. Estimates of Price and Income Elasticies of Demand for Water in Industrial Use in the Red River. Report prepared for the U.S. Army Corps of Engineers, Tulsa District. Tulsa, Oklahoma.

Abstract:

This report describes an analysis of the use of self-suppled water by 84 firms within six two-digit SIC categories. Food, lumber, paper, chemicals, petroleum, and clay industries were included. The estimated equations for these categories are:

(1) Food industry (SIC 20)

$$\ln Q = \underset{(-13.79)}{-5.4358} - \underset{(-3.85)}{2.4186} \ln P_w + \underset{(3.55)}{0.6385} \ln X$$

$R^2 = 0.84$ F = 54.92 d.f. = 2,21

(2) Lumber industry (SIC 24)

$$\ln Q = \underset{(-11.56)}{3.8097} - \underset{(-0.92)}{0.5570} \ln P_w + \underset{(5.63)}{1.0183} \ln X$$

$R^2 = 0.98$ F = 72.86 d.f. = 2,3

(3) Paper industry (SIC 26)

$$\ln Q = \underset{(-2.61)}{-3.6829} - \underset{(-2.48)}{0.5624} \ln P_w + \underset{(3.24)}{1.994} \ln X$$

$R^2 = 0.66$ F = 10.51 d.f. = 2,11

(4) Chemical industry (SIC 28)

$$\ln Q = \underset{(-7.91)}{-5.6649} - \underset{(-4.05)}{1.4668} \ln P_w + \underset{(3.71)}{0.9930} \ln X$$

$R^2 = 0.69$ F = 17.18 d.f. = 2,15

(5) Petroleum industry (SIC 29)

$$\ln Q = \underset{(-12.16)}{-4.8470} - \underset{(-2.60)}{0.1522} \ln P_w + \underset{(11.79)}{1.0610} \ln X$$

$R^2 = 0.95$ F = 82.41 d.f. = 2,9

(6) Stone and clay industry (SIC 32)

$$\ln Q = \underset{(-8.72)}{-3.2937} - \underset{(-2.08)}{1.1271} \ln P_w + \underset{(5.98)}{0.6726} \ln X$$

$R^2 = 0.92$ F = 45.37 d.f. = 2,7

Where: Q = daily water intake by an industrial plant in million gallons per day (mgd); P_w = unit cost of water including purchase price and cost of treatment within the plant before discharge, and the cost of pumping and transmission applicable to self-supplied plants; ($/1,000 gallons); X = annual sales of the plant in million dollars. Since the "price" variable is actually average cost, there is some doubt whether demand functions have been estimated.

Data Base Information:

Study Area Data

Location and water users: 84 industrial plants in Red River Basin (Northwest Louisiana to Northwest Texas).
Mean summer temperature: 76.5 degrees F.
Mean summer precipitation: 1-14 inches.
Mean summer evapotranspiration: 17-20 inches.
Mean summer moisture deficit: 11.6-16.4 inches.
Water rates: varying rates for purchased water, additional unit cost related to water included.
User sector: industrial.
Area character: not reported, multi-site.

Water Use Data

Maximum number of cases: 24 plants in SIC category 20.
Type of measurement: secondary; industrial pumpage and metering records.
Measurement period: 1978.
Dependent variable: purchased or pumped quantity of water in million gallons per day (annual average).
Estimating technique: OLS regression.
Price variable specification: average price of supplying and treating water, including cost of treating wastewater.

Means (coefficients of variation) and price elasticities:

SIC 20:
Q = 0.806 (2.008) mgd.
P_w = 0.466 (0.407) $/1,000 gallons.
X = 30.358 (1.155) million $.
Elasticity = -2.42.

SIC 24:
Q = 0.165 (0.811) mgd
P_w = 0.453 (0.219) $/1,000 gallons.
X = 4.386 (0.748) million $.
Elasticity = -0.56.

SIC 26:
Q = 10.267 (0.752) mgd.
P_w = 0.248 (0.818) $/1,000 gallons.
X = 54.107 (0.486) million $.
Elasticity = -0.56.

SIC 28:
Q = 0.499 (1.360) mgd.
P_w = 0.389 (0.512) \$/1,000 gallons.
X = 13.827 (0.947) million \$.
Elasticity = -1.47.

SIC 29:
Q = 1.319 (0.868) mgd.
P_w = 0.340 (0.333) \$/1,000 gallons.
X = 101.050 (0.730) million \$.
Elasticity = -0.15.

SIC 32:
Q = 0.781 (0.694) mgd.
P_w = 0.438 (0.259) \$/1,000 gallons.
X = 19.792 (0.633) million \$.
Elasticity = -1.13.

5 Billings, R. B. and D. E. Agthe. 1980. Price Elasticities for Water: A Case of Increasing Block Rates. Land Economics 56(1):73-84.

Abstract:

The authors of this article present an analysis of alternative specifications of price variables in water demand models, followed by estimation of demand functions for Tucson, Arizona. Both linear and double-log models, each one including two price-related variables (marginal price and Nordin's bill difference construct), were fitted to 45 time-series measurements of aggregate residential monthly water use data expressed in 100 cubic feet per average household.

The estimated equation for the linear model is:

$$(1)\quad Q = \underset{(0.8)}{-14.2} - \underset{(3.2)}{0.331}\, P_{ms} - \underset{(4.3)}{1.96}\, D + \underset{(2.4)}{0.0467}\, I + \underset{(10.6)}{0.0147}\, M$$

$$R^2 = 0.82 \quad F = 46.9 \quad \text{d.f.} = \text{N.R.} \quad \text{D-W} = 2.09$$

Where: all variables correspond to monthly time intervals and to the average household in the study area. The M variable denotes monthly evopotranspiration minus rainfall, and I is personal income per household in dollars per month. Each regression coefficient is statistically significant at 0.025 probability level. The price elasticity in the above model obtained by multiplying the price coefficient by P_{ms}/Q (means) is reported to be -0.49, while the elasticity of bill difference is -0.14.

The estimated double-log equation is:

$$(2)\quad \ln Q = \underset{(1.3)}{-7.36} - \underset{(1.6)}{0.267} \ln P_{ms} - \underset{(5.2)}{0.123} \ln D + \underset{(1.9)}{1.61} \ln I + \underset{(9.6)}{0.0897} \ln W$$

$$R^2 = .83 \quad F = 49.9 \quad \text{d.f.} = \text{N.R.} \quad \text{D-W} = 1.83$$

with each regression coefficient significant at 0.10 level. The marginal and bill difference elasticities corresponding to those in the linear equation are -0.267 and -0.123, respectively. The authors did not present a price elasticity result which accounts for the effect of price on the value of the bill difference term.

The regression estimates in both models were judged by the authors as free of serial correlation, based on the values of Durbin-Watson statistics.

Data Base Information:

Study Area Data

Location and water users: Tucson, Arizona; average residential households including all single-family residences, apartments, condominiums, mobile homes, duplexes, and triplexes served by individual water connections (multiple units with common water meter are excluded).
Mean summer temperature: 86 degrees F.
Mean summer precipitation: 5 inches.
Mean summer evapotranspiration: 27 inches.
Mean summer moisture deficit: 18 inches.
Water rates: increasing block with service charge.
User sector: all residential.
Area character: urban, suburban.

Water Use Data

Maximum number of cases: 45.
Type of measurement: secondary, not specified.
Measurement period: January 1974-September 1977.
Dependent variable: monthly water use of the average household in 100 cubic feet/month.
Summer season definition: not reported.
Winter season definition: not reported.
Price variable specification:
(1) marginal real price facing the average household in cents per 100 cubic feet.
(2) Nordin's bill difference calculated as the "typical consumer's" actual water and sewer use bill minus what would have been paid if all water was sold at the marginal price.
Estimating technique: ordinary least squares.
Special circumstances: introduction of sewer user charges, three changes of water rates.

Minimum, maximum, and mean variable values:

Q (mean) = 17.8 CCF/month. No minimum or maximum values reported.
Pms = 21, 42, 26.3 cents.
D (difference term) = 0.24, 2.08, 1.24 dollars.

Price elasticities(n):

n_p = -0.45 to -0.61, -0.49 (linear equation).
n_p = -0.267 (double-log equation).
n_D = -0.030 to -0.21, -0.14 (linear model).
n_D = -0.123 (double-log equation).

No estimate is provided of total price elasticity, considering both price and effect of price on bill difference.

6 Billings, R. B. 1982. Specification of Block Rate Price Variables in Demand Models. Land Economics 58(3):386-94.

Abstract:

This is a follow-up article to the study of residential water demand in Tucson, Arizona, originally reported in Billings and Agthe (1980). In order to refine two price-related variables the author uses a procedure that regresses the values of total revenue against their corresponding water consumption values, so that each legal rate structure is represented by a constant marginal price, P*, and a constant Nordin's bill difference variable, D*.

Using these newly defined variables the author reestimated the coefficients reported in the 1980 article. The reestimated equation of the linear model is:

$$(1)\quad Q = \underset{(1.1)}{-17.8} - \underset{(5.3)}{0.425}\,P^* - \underset{(2.4)}{1.19}\,D^* + \underset{(2.7)}{0.0521}\,I + \underset{(12.7)}{0.0167}\,M$$

$R^2 = 0.82$ F = N.R. d.f. = 4,44

while the reestimated double-log equation is:

$$(2)\quad \text{Log } Q = \underset{(1.8)}{-9.54} - \underset{(4.1)}{0.561}\,\log P^* - \underset{(3.1)}{0.0875}\,\log D^* + \underset{(2.4)}{2.14}\,\log I + \underset{(12.2)}{0.101}\,\log M$$

$R^2 = 0.81$ F = N.R. d.f. = 4,44

In comparison to the original equation, the above estimates of slope and elasticity of marginal price are substantially larger for both linear and double-log formulations. The new price elasticities are -0.66 and -0.56 for linear and log-linear model, respectively, as opposed to the original estimates of -0.49 and -0.27. The corresponding elasticities of the Nordin's bill difference variable are -0.075 and -0.087, as opposed to -0.14 and -0.12 in the old equation. The author does not indicate whether the bill difference term is itself a function of marginal price.

Data Base Information:

See Billings and Agthe (1980).

Price elasticities: -0.66 (linear), -0.56 (double-log).
Difference elasticities: -0.075 (linear), -0.087 (double-log).

7 Camp, R. C. 1978. The Inelastic Demand for Residential Water: New Findings. Journal of American Water Works Association 70(8):453-58.

Abstract:
This article describes the estimation of residential water demand models for a sample of 288 single-family households randomly selected from 10 service areas in northern Mississippi. Ten multiple regression equations, with the dependent variable defined as annual household water consumption, were estimated. However, two equations are reported here.

The first seven variables in the linear equation below have coefficients significant at the 0.05 level or better:

$$(1)\ Q = -114.25 + \underset{(8.09)}{9.61\ H} + \underset{(2.27)}{0.11\ L_w} + \underset{(2.60)}{13.61\ A_c}\ \underset{(5.35)}{137.53\ X_1}$$

$$- \underset{(-1.97)}{0.60\ F} - \underset{(-3.03)}{18.32\ P_{ms}} + \underset{(4.20)}{8.57\ X_2} + \underset{(0.08)}{0.01 X_3} + \underset{(1.33)}{0.04\ Y_m} + \underset{(0.91)}{4.40\ A_b}$$

$$+ \underset{(0.58)}{3.30\ A_d} + \underset{(0.21)}{1.17\ X_4} + \underset{(1.66)}{2.63\ T}$$

R^2adj. = 0.60 F = N.R. d.f. = N.R.
Price elasticity = -0.24.

Where: L_w = irrigable lawn area in 100 sq. ft., X_1 = presence of swimming pool; X_3 ≐ age of head of household; A_b = number of bathrooms; A_d = number of dishwashers; X_4 = race; and T = average *maximum temperature for the area.*

The second equation reported included six explanatory variables significant at 0.05 level of probability:

$$(2)\ Q = 331.9 + \underset{(9.80)}{32.50 \log H} + \underset{(2.56)}{0.126\ L_w} + \underset{(2.00)}{10.28\ A_c} + \underset{(5.89)}{145996.5 \log X_5}$$

$$\underset{(-4.29)}{-22.81 \log P_{ms}} + \underset{(4.14)}{7.62\ X_2} + \underset{(1.92)}{0.004\ Y_m} - \underset{(-1.85)}{31.77 \log F}$$

R^2adj. = 0.58 F = N.R. d.f. = N.R.
Price elasticity = -0.30.

Where: X_5 denotes the existence of a swimming pool at the residence.

Among the remaining regression equations which are not presented in the article, five had all explanatory variables significant at the 0.10 probability level. Price elasticities for all 10 models varied from -0.03 to 0.40. The statistical data on mean variable values, errors of regression coefficient and intercorrelation coefficients are included.

Data Base Information:

Study Area Data

Location and water users: 288 single-family residences in 10 cities in Northern Mississippi, ranging in population from 5,000 to 20,000.
Mean summer temperature: 75-80 degrees F.
Mean summer precipitation: 10 inches.
Mean summer evapotranspiration: 19 inches.
Mean summer moisture deficit: 13 inches.
Water rates: varied due to multi-site study area.
User sector: single-family residential.
Area character: urban, suburban.

Water Use Data

Maximum number of cases: 288.
Type of measurement: secondary, individual water bills.
Measurement period: N.R. (probably mid-1970s).
Dependent variable: annual domestic water consumption per customer in 1,000 gallons per year.
Summer season definition: not reported.
Winter season definition: not reported.
Estimating technique: stepwise least squares regression.
Price variable specification: nominal marginal price of water in each city at the mean level of consumption for all domestic users included in the entire study in $/1,000 gallons.

Minimum, maximum, and mean variable values:

Q = 48-119, 71 in 1,000 gallons/customer/year.
P_{ms} = \$0.45-\$1.65, \$0.93/1000 gallons.
H = 2.7-3.6, 3.2 number of occupants/household.
A_c = 0.64-0.86, 0.77 number of clothes washers.
X_2 = 1.20-4.03, 1.93 education index of the household head.
Y_m = 67-237, 113.7 market value of residence in 100's dollars.

Price elasticity: -0.03 to -0.40; -0.29 (minimum, maximum, and mean).

8 Carver, P. H. 1978. Price as a Water Utility Management Tool Under Stochastic Conditions. Ph.D. diss. Department of Geography and Environmental Engineering. Johns Hopkins University, Baltimore, Maryland.

Abstract:

This dissertation includes two empirical studies of water demand. The first was also published as Carver and Boland, "Short- and Long-run Effects of Price on Municipal Water Use," and is abstracted under that title. The second analysis is reviewed here.

Fairfax County Water Authority implemented a novel summer surcharge rate structure during the period 1974-76. Water rates changed from a $0.58/1,000 gallon uniform charge in 1974 to a $0.64 uniform charge with a $1.00 surcharge in 1975, to a $0.60 uniform charge with a $2.00 surcharge in 1976. In every case the surcharge applied to use in excess of 1.3 times the previous winter quarter. Carver's study attempted to determine the short-run response to that rate structure change.

Water use data were obtained for single-family residential users for each quarter during the period 1974-76; descriptive statistics were calculated, and examined for differences which could be associated with the rate structure changes. Other user classes were studied, but no consistent results obtained. Data for 1973 were collected but not used in the elasticity calculations. For the single-family residential class, no significant differences were found in the means, but the coefficient of variation was observed to drop on first implementation of the summer surcharge (1974). This drop was attributed to large use reductions by relatively few large summer users. Seasonal use ratios were also calculated (seasonal use/annual use), then regressed on moisture deficit. A significant shift in the regression line was observed for the postimplementation data.

Arc price elasticities were calculated for the summer seasonal use of those single-family residential customers subject to the excess use charge (the largest 30 percent). These customers were analyzed in five percentile groups. Seasonal water use was calculated for each group, then normalized to 1975 weather, using moisture, using moisture deficit data. Separate calculations were made for the 1974-75 period (real marginal price increased 164.3 percent) and for the 1974-76 period (real marginal price increased 295.7 percent). Arc elasticities ranged from -0.13 to -0.17 in the first case, and from -0.02 to -0.04 in the second.

Data Base Information:

Study Area Data

Location and water users: Fairfax County, Virginia (Washington, D.C., metropolitan area); 52,598 (1973) to 69,153 (1976) single-family residential users.
Mean summer temperature: 75 degrees F.
Mean summer precipitation: 10 inches.
Mean summer evapotranspiration: 18 inches.
Mean summer moisture deficit: 2.69-2.90 inches.

Water rates: prior to June 1975—uniform price; July 1975-December 1976—uniform price plus a surcharge for all use in excess of 1.3 times previous winter quarter.
User sector: single-family residential.
Area character: surburban.

Water Use Data

Maximum number of cases: four (arc elasticity calculations based on totals for user class).
Type of measurement: secondary.
Measurement period: January 1974-December 1976.
Dependent variable: Seasonal water use during summer quarter, aggregated over single-family residential class.
Summer season definition: billing quarters ending August, September, and October.
Winter season definition: billing quarters ending February, March, and April.
Estimating technique: calculation of arc elasticities.
Price variable specification: real marginal price (1975 dollars) for all users in sample; $/1,000 gallons.
Special circumstances: study deals with implementation of novel rate structure; rate structure was announced November 1974 but not implemented until June 1975.

Minimum, maximum, and mean variable values: no minimum or maximum values provided; mean values presented.

Seasonal water use:
1974—5,150 gallons/connection/quarter.
1975—2,880 gallons/connection/quarter.
1976—5,100 gallons/connection/quarter.
Summer moisture deficit:
1974—2.76 inches.
1975—2.69 inches.
1976—2.90 inches.
Real marginal price:
1974—$0.58/1,000 gallons.
1975—$1.53/1,000 gallons (for users paying surcharge).
1976—$2.30/1,000 gallons (for users paying surcharge).

Price elasticities: 1974-75 arc elasticities = -0.13 to -0.17; 1974-76 arc elasticities = -0.02 to -0.04.

9 Carver, Phillip H., and John J. Boland. 1980. Short- and Long-Run Effects of Price on Municipal Water Use. Water Resources Research 16(4):609-16.

Abstract:

The purpose of this study was to evaluate the effects of price changes on water consumption both in the short run (one to two years) and in the long run. Monthly aggregate water production data were collected from 13 Washington, D.C., area water utilities serving residential areas for 1969 through 1974.

Two separate sets of regressions for seasonal and nonseasonal pooled time-series and cross-sectional data sets are evaluated. Nonseasonal use is estimated as water use during the months November through April. Seasonal use is derived by subtracting the mean water use for the months of January, February, November, and December from the usage for May through October in the same year. Therefore, six observations of both seasonal and nonseasonal were available for each year. Lagged consumption is included in the regressions as an explanatory variable and is based on a one-year lag.

Five regressions are obtained for each of the pooled time series data sets: (1) ordinary least squares (OLS) without lagged consumption, (2) OLS with lagged consumption, (3) least squares with dummy varibles (LSDV), for cross-sectional units only, (4) LSDV time series only, and (5) LSDV pooled.

Presented here are the results of the OLS with lagged consumption:

(1) Nonseasonal

$$Q_n = -23.6 - \underset{(11.5)^*}{33.9\, P_{ms}} + \underset{(0.0019)}{0.0018\, I} + \underset{(3.78)}{2.88\, E} + \underset{(4.8)^*}{12.0\, H} + \underset{(0.023)^*}{0.928\, X}$$

R^2adj. = 0.970 F = N.R. N = 373

Short-run price elasticity = -0.05*.

Long-run price elasticity = -0.70*.

(2) Seasonal

$$Q_s = -108.9 - \underset{(10.7)}{10.6\, P_{ms}} + \underset{(0.0018)}{0.0016\, I} + \underset{(3.34)^*}{8.14\, E} + \underset{(4.71)^*}{22.8\, H} + \underset{(1.96)^*}{19.7\, M}$$

$$+ \underset{(0.046)^*}{0.142\, X}$$

R^2adj. = 0.454 F = N.R. N = 376

Short-run price elasticity = -0.10.

Long-run price elasticity = -0.11.

Where: Q = water usage (gallons/connection/day); P_{ms} = average incremental price over the range of 17,000-27,000 gallons per quarter (1966$/1,000 gallons); I = income per household (1966$); E = number of employees per connection; H = number of residents per connection; X = lagged consumption coefficient; and M = moisture deficit (inches/month).

The asterisk indicates significance at the 0.05 probability level for a one-tailed t-test; all others are significant at the 0.20 level or better.

The authors indicate that based on an assumed error components model the long-run price elasticity for nonseasonal use may have been overestimated but could be within the range of values predicted in previous cross-sectional studies. The nonseasonal, short-run elasticity indicates that the response to price changes in the short-run are quite small.

The two OLS (lagged) seasonal estimates of price elasticities were significant only at the 0.20 level (other seasonal regression estimates were nonsignificant). These seasonal estimates are much lower than those estimated previously (Howe and Linaweaver 1967). The author's state that "the short-run seasonal elasticity might be larger (in absolute value) than for nonseasonal use, but the variance is so high that the hypothesis that the response is less cannot be rejected at the 0.05 significance level."

Data Base Information:

Study Area Data

Location and water users: 13 Washington, D.C., area water utilities.
Mean summer temperature: 75 degrees F.
Mean summer precipitation: 10 inches.
Mean summer evapotranspiration: 18 inches.
Mean summer moisture deficit: 12 inches.
Water rates: mixed rates due to the sample of 13 utilities.
User sector: aggregate municipal (primarily residential users).
Area character: urban.

Water Use Data

Maximum number of cases: 376 observations (seasonal); 373 observations (nonseasonal).
Type of measurement: aggregate water production records.
Measurement period: 1969-74.
Dependent variable: average daily water use (gallons/connection/day).
Summer season definition: May-October (seasonal use).
Winter season definition: November-April (nonseasonal use).
Estimating technique: OLS regression.
Price variable specification: the average incremental (marginal) price per 1,000 gallons over the range of 17,000-27,000 gallons quarter (deflated to 1966 dollars).

Minimum, maximum, and mean variable values: no mean values reported.
Minimum and maximum values are presented.

P = 0.28-$1.55/1,000 gallons.
Q_s = -95-409 gallons/connection/day.
Q_n = 138-1,429 gallons/connection/day.
I = $7,456-$16,709/year.
H = 2.83-6.58 persons/connection.
E = 0.49-5.42 employees/connection.

Price elasticities:
Short-run (OLS lagged) = -0.05 (nonseasonal); -0.10 (seasonal).
Long-run (OLS lagged) = -0.70 (nonseasonal); -0.11 (seasonal).

Note: nonseasonal elasticities are significant at the 0.05 level; seasonal elasticities are significant at the 0.20 level.

AD-A145 092 INFLUENCE OF PRICE AND RATE STRUCTURES ON MUNICIPAL AND INDUSTRIAL WATER..(U) PLANNING AND MANAGEMENT CONSULTANTS LTD CARBONDALE IL J J BOLAND ET AL. JUN 84 2/3

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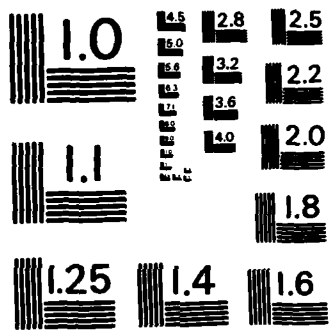
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10 Cassuto, Alexander E., and Stuart Ryan. 1979. Effect of Price on the Residential Demand for Water within an Agency. Water Resources Bulletin 15(2):345-53.

Abstract:

The authors of the article develop a "model that can be used to forecast the residential elasticity of demand for water within a district." The study utilizes data for 246 census tracts within the East Bay Municipal Utility District in urban Oakland, California. The study uses pooled cross-sectional and time-series data for 72 months (1970-75) to develop a model in linear and logarithmic forms. The dependent variable is average residential water consumption which is calculated by dividing "total [monthly] water consumption of separately metered single-family dwellings by the number of active single family accounts in the tract." The following are utilized as independent variables in the regression equation: average number of persons per household; real mean family income ($100); weekdays during the month; average elevation of the census tract; average residential lot size; temperature; actual price of water in the first block; energy price index; time trend; days per month; and precipitation.

Two methods are used to estimate the dependent variable: ordinary least squares regression and stepwise regression. However, no coefficients or significance tests are reported. To estimate price elasticity two price variables are used: absolute price and a lagged price. The absolute price is the price per unit of the first 4,000 cubic feet of water per month, since over 99 percent of the residential single family customers fell within this range. "The price per hundred cubic feet of water consumed in this block was 22 cents from 1969 through March 1973; 23 cents until April 1974; and 24 cents through the study period." The lagged price variable is utilized by "staggering the effect of price increases over ten months following the actual rate change." The water price elasticities for all census tracts are:

	OLS	Stepwise
absolute price elasticity	-0.300	-0.142
lagged price elasticity	-0.207	-0.141

Where: the OLS estimates are statistically significant at the 0.01 level and the stepwise estimates are significant at the 0.05 level.

A second model included only those census tracts that had 90 percent or more single-family to total housing units. The price elasticities for this more homogeneous sample are estimated as such:

	OLS	Stepwise
absolute price elasticity	-0.387	-0.161
lagged price elasticity	-0.300	-0.159

Where: the OLS and stepwise estimates are statistically significant at the 0.01 and 0.05 levels, respectively. The author's conclude that within the district's price range the demand for water was "relatively insensitive to price changes."

The data that were utilized in the regression model are not clearly specified. Furthermore, the regression coefficients of the model and significance tests were not reported.

Data Base Information:

Study Area Data

Location and water users: residential water users within 246 census tracts in Oakland, California.
Mean summer temperature: 65 degrees F.
Mean summer precipitation: 1 inch.
Mean summer evapotranspiration: 10 inches.
Mean summer moisture deficit: 9.4 inches.
Water rates: uniform to first 4,000 cubic feet (99 percent of customers in this range).
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: 246 tract times 72 months.
Type of measurement: aggregate water sales within census tracts.
Measurement period: January 1970-December 1975, 72 months.
Dependent variable: average monthly residential water consumption.
Summer season definition: not specified.
Winter season definition: not specified.
Price variable specification: marginal price for average user in sample.
Estimating technique: ordinary least squares and stagewise regression.

Minimum, maximum and mean variable values: no mean values reported.

I = $4,900-$25,900/year.
H = 1.24-4.79 persons/household.
L = 0.082-0.327 acres/household.

Price elasticity: note text.

11 Clark, Robert M., and Haynes C. Goddard. 1977. Cost and Quality of Water Supply. Journal of the American Water Works Association 69(1):13-15.

Abstract:

Although the main intent of this study was to evaluate the factors which influence the price of water, the price elasticity of consumer demand is also calculated. Cross-sectional data for 22 community water supply systems in the Cincinnati, Ohio (SMSA) are analyzed. Although the authors indicate that the majority of the consumption is for domestic use, the data base is aggregate municipal use. Average daily per capita demand for water (gpcd) is the dependent variable; and price and income are independent variables. Using only price as an independent variable, two forms of the model are presented:

(1) Linear

$$Q = 144.577 - \underset{(-4.22)}{85.329}\, P_{ms}$$

$R^2 = 0.45$ F = N.R. Df = 1,20

(2) Double-log

$$\text{Log } Q = 1.771 - \underset{(-3.761)}{0.602}\, P_{ms}$$

$R^2 = 0.38$ F = N.R. df = 1,20

The values in parentheses are t-values. The price elasticity of demand calculated at the mean of the linear model is -0.63 and calculated from the double-log model is -0.602. The elasticities are significantly different from zero at the 0.05 level.

The linear model including income as an independent variable indicates the following relationship:

(3) $$Q = 130.882 - \underset{(-4.39)}{87.688}\, P_{ms} + \underset{(1.26)}{0.0043}\, I$$

$R^2 = 0.46$ F = N.R. Df = 2,19

Price elasticity (at the means) is -0.63.

Data Base Information:

Study Area Data

Location and water users: 22 waterworks systems in Cincinnati, Ohio (SMSA).
Mean summer temperature: 74-75 degrees F.
Mean summer precipitation: 8-10 inches.

Mean summer evapotranspiration: 15-16 inches.
Mean summer moisture deficit: 9.0-11.2 inches.
Water rates: not clearly specified although indicates a block rate structure.
User sector: aggregate municipal.
Area character: urban, suburban.

<u>Water Use Data</u>

Maximum number of cases: 22 observations.
Type of measurement: secondary data from EPA's community water supply survey (CWSS) and the U.S. Census.
Measurement period: 1969 and 1970.
Dependent variable: average daily per capita demand (gallons/capita/per day).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: multiple regression.
Price variable specification: marginal price for average user in sample, i.e., price in first consumption block ($/1,000 gallons).

Minimum, maximum, and mean variable values:

Q = 32-188, 91.5 gallons/capita/day.
I = $2,307-$10,268, $3,542.91
P_{ms} = $0.20-$1.30, $0.66/1,000 gallons.

Price elasticities: -0.63 linear and -0.60 log.

12

Conley, Bryan C. 1967. Price Elasticity of the Demand for Water in Southern California. Annals of Regional Science 1(1):180-89.

Abstract:

Using data from the 1955 survey of water utilities by the American Water Works Association, the author selected 24 communities located in Southern California to estimate residential demand. Using a log-linear model, the estimated equation is:

$$(1)\ \text{Log } Q = 7.56 + \underset{(0.51)}{0.076} \log MP_1 + \underset{(0.30)}{0.060} \log MP_2 - \underset{(4.95)}{1.091} \log AP$$

$R^2 = 0.53$ F = N.R. d.f. = 3,20

Where: Q = per capita daily residential use in gallons (based on annual data); MP_1 = monthly marginal price for first 1,000 gallons; MP_2 = monthly marginal price for the first 10,000 gallons; and AP = average price per 1,000 gallons, derived by dividing total revenues by number of 1,000 gallon units delivered. Marginal price is also calculated as an average for the utilities. In equation (1), both marginal price coefficients were nonsignificant and displayed the wrong signs. The elasticity with respect to average price, -1.09, is significant at the 0.05 level.

Equation (2) is presented with only average price as an independent variable:

$$(2)\ \text{Log } Q = 8.20 - \underset{(4.88)}{1.025} \log AP$$

$R^2 = 0.522$ F = N.R. d.f. = 1,22

The average price elasticity is -1.02 and is significant; therefore the author concludes that average price is better than marginal price as an indicator of residential demand.

After summarizing other residential demand studies, the author states that, despite his results "econometric evidence suggests an elasticity of -0.35 for household uses in Southern California."

Data Base Information:

Study Area Data

Location and water users: 24 communities in Southern California.
Mean summer temperature: 70-80 degrees F.
Mean summer precipitation: 0-1 inch.
Mean summer evapotranspiration: 10-15 inches.
Mean summer moisture deficit: 9-15 inches.
Water rates: not specified; however, due to multisite data it can be assumed that there were mixed rates.
User sector: all residential.
Area character: urban.

Water Use Data

Maximum number of cases: 24 observations.
Type of measurement: secondary data from 1955 AWWA survey (annual residential water sales divided by the number of services).
Measurement period: 1955.
Dependent variable: daily use per capita.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: multiple regression.
Price variable specification: (1) average price for all customers of utilities; (2) marginal price for average users in sample.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: -1.02 to -1.09 (log with average price).

13

Danielson, Leon E. 1979. An Analysis of Residential Demand for Water Using Micro Time-Series Data. Water Resources Research 15(4):763-67.

Abstract:

This study describes an analysis of water use data obtained from 68 monthly billing records for 261 households in Raleigh, North Carolina. The sample period, extending from May 1969 to December 1974, covered three price increases. The relations of water use and six explanatory variables were estimated for total household demand (domestic plus sprinkling), using double-log models.

The reported equation for total household demand is:

$$(1)\ \log Q_t = \underset{(1.86)}{-0.350} - \underset{(3.00)}{0.018} \log F + \underset{(11.28)}{0.316} \log T + \underset{(20.88)}{0.334} \log Y$$

$$\underset{(4.32)}{-0.272} \log P_{mc} + \underset{(43.53)}{0.740} \log H$$

Where: Q_t = average household water consumption in gallons per day ; F = average daily rainfall during a billing period (units not reported); T = average temperature during billing periods (units not reported); Y = appraised house and lot value of the residential customer; P_{ms} = first block price of water including 50 percent sewerage charge per 1,000 gallons adjusted to real price using CPI; and, H = household size or number of persons per household. The author made adjustments for serial correlation using the method described by Kmenta (Elements of Econometrics, 1971). All reported coefficients are significant at the 0.01 probability level (one-tailed t-test). Coefficients of determination (R^2) are not reported, being invalid because of data tranformations made to overcome serial correlation.

The estimated equation for winter demand is:

$$(2)\ \log Q_w = \underset{(3.99)}{0.849} + \underset{(16.0)}{0.352} \log Y - \underset{(3.59)}{0.305} \log P_{ms} + \underset{(26.50)}{0.689} \log H$$

Where: Q_w = average household water consumption during November through April in gallons per day. The corresponding equation for sprinkling demand is:

$$(3)\ \log Q_s = \underset{(8.60)}{-26.204} - \underset{(3.43)}{0.206} \log F + \underset{(7.72)}{5.141} \log T + \underset{(4.03)}{0.363} \log Y$$

$$- \underset{(3.48)}{1.38} \log P_{ms}$$

Where: Q_s = average household spinkling use estimated by subtracting, for each customer, winter use from total household use.

Price elasticities for the three types of water use, in the double-log equations, were -0.272, -0.305, and -1.38, respectively. Overall, the study seems to provide valid estimates of price elasticity, although the failure of the author to report average or mean values for some explanatory variables makes the verification of the reported data impossible.

Data Base Information:

Study Area Data

Location and water users: 261 households in Raleigh, North Carolina.
Mean summer temperature: 77 degrees F.
Mean summer precipitation: 16 inches.
Mean summer evapotranspiration: 17 inches.
Mean summer moisture deficit: 7.4 inches.
Water rates: uniform; all customers in first block (including sewer charge.
User sector: residential, single-family.
Area character: urban.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: secondary, individual users.
Measurement period: May 1969-December 1974.
Dependent variable: average household water consumption (gallons/day); average household consumption during winter season (gallons/day); average household sprinkling use (gallons/day).
Summer season definition: May-October.
Winter season definition: November-April.
Estimating technique: ordinary least squares regression.
Price variable specification: marginal price for each user.

Minimum, maximum, and mean variable values:

Q_t = mean: 205.9 gallons/household/day.
Q_s = mean: 27 gallons/day.
P_{ms} = not reported.
Y = mean: $18,376.
H = mean: 3.07 persons/household.

Price elasticities: -0.272 (total residential), -0.305 (winter), -1.38 (sprinkling).

14

DeRooy, Y. 1974. Price Responsiveness of the Industrial Demand for Water. Water Resources Research 10(3):403-06.

Abstract:

The purpose of this study was to estimate the effects of price, output, technological improvements, and employment on the demand for water based on water use data for 30 large chemical manufacturing plants in northern New Jersey during the year 1965.

The equation for cooling water demand estimated using OLS regression was found to be:

$$(1)\ \log Q = -0.757 + \underset{(5.36)}{1.212} \log X_t - \underset{(-4.99)}{0.894} \log P - \underset{(-3.44)}{0.580}\ T$$

$R^2 = 0.81$ F = N.R. d.f. = 3,24

Where: Q = firm's annual demand for cooling water in 1,000 gallons; X_t = output of the firm in \$1,000; P = total cost of water in \$/1,000 gallons; and, T = technology index expressed as the first principal component of five technological variables (value added per production employee, mean hourly wage, age of the plant, product group variable, and labor-output ratio).

The OLS estimation did not produce significant regression coefficients for price variable in the equations for processing water demand and demand for steam power water. These coefficients were reestimated by applying a "mixed regression" technique developed by Theil and Goldberger. The revised regression equation for processing water is:

$$(2)\ \log Q = -1.683 + \underset{(8.73)}{1.220}\ X_t - \underset{(4.82)}{0.745}\ P - \underset{(3.20)}{0.480}\ T$$

d.f. = 3,19

and for steam generation water:

$$(3)\ \log Q = -1.858 + \underset{(8.21)}{1.192}\ X_t - \underset{(4.56)}{0.741}\ P - \underset{(5.24)}{0.862}\ T$$

d.f. = 3,20

The demand for sanitation water was found to be influenced significantly only by the total employment in the plant (E):

$$(4)\ Q = \underset{(13.99)}{16.744}\ E$$

R^2adj. = 0.92 d.f. = 1,16

Mean employment in the sample was 844 with coefficient of variation of 122.8. Since the "price" variable is primarily a measure of internal unit cost, there is some doubt whether demand functions have been estimated.

Data Base Information:

Study Area Data

Location and water users: 30 large manufacturing plants in chemical and allied industries located in northern New Jersey.
Mean summer temperature: 70-75 degrees F.
Mean summer precipitation: 6 inches.
Mean summer evapotranspiration: 14 inches.
Mean summer moisture deficit: 10.4 inches.
Water rates: not reported.
User sector: industrial (purchased and self-supplied).
Area character: not reported, multi-site.

Water Use Data

Maximum number of cases: 28 plants for a specific use category.
Type of measurement: secondary, water intake records.
Measurement period: 1965.
Dependent variable: gross water use for specific purpose (the intake that would be required if no water was recycled), in 1,000 gallons/year.
Estimating technique: OLS, "mixed regression" as described in Theil and Goldberger, (J. Amer. Statist. Ass. 58 [1963]:401-14).
Price variable specification: the sum of three unit costs:
(1) weighted unit cost of intake purchased from a public utility and the intake pumped from a well or stream;
(2) unit cost of any treatment prior to use; and
(3) unit cost of disposal (including any waste treatment) in \$/1,000 gallons.

Means (coefficients of variation) and price elasticities:

Cooling water:
Q = 2,421,159 (189.4) 1,000 gallons.
P = 0.305; (266.4) \$/1,000 gallons.
X_t = 23,486 (122.8) \$1,000.
Elasticity = -0.894.

Processing water:
Q = 154,427 (199.2).
P = 0.490 (88.5).
X_t = 24,497 (123.8).
Elasticity = -0.745 x P (mean) = -0.745 x 0.490 = -0.365.

Steam generation water:
Q = 93,309 (159.2).
P = 0.649 (118.2).
X_t = 22,869 (126.5).
Elasticity = -0.741 x P (mean) = -0.649 = -0.481.

15

Elliot, Ralph D., and James A. Seagraves. 1972. <u>The Effects of Sewer Surcharges on the Level of Industrial Wastes and the Use of Water by Industry.</u> Water Resources Research Institute, Report no. 70. University of North Carolina. Raleigh.

Abstract:

The purpose of this study was to evaluate responses to industrial waste surcharges. The two objectives were to estimate the effects of surcharges (1) on the quantity of waste discharged and on (2) the quantity of water demanded. The sample includes a cross-section of 34 cities in the United States that utilized surcharges. Annual observations on consumption and other variables were obtained from 1957 to 1970, however, not all cities reported data for these years. Therefore, the sample included 198 observations for the 34 cities. "The data base contained mostly cross-sectional variation and the time series component of the data did not contain enough variation to estimate the industrial response to surcharges within cities." In a preliminary analysis it was found that the linear model produced the highest R^2 value and that the presence of a food and kindred industry had a strong positive effect on water usage within these cities. The estimated OLS regression equation for the industrial demand for water is:

$$Q = 2.22 - \underset{(-3.58)}{36.79\, P_{ms}} - \underset{(-4.18)}{0.52\, X_1} + \underset{(2.68)}{8.63\, X_2} + \underset{(5.16)}{75.10\, FK}$$

$$R^2 = 0.32 \qquad F = \text{N.R.} \qquad \text{d.f.} = 4{,}174$$

Where: Q = gallons of water per day per \$1,000 value added in manufacturing; P_{ms} = net marginal cost of water and normal sewer in \$/1,000 gallons; X_1 = the surcharge in dollars per 1,000 pounds of BOD; X_2 = the price of labor in dollars per hour; and FK = the proportion of city value added accounted for by food and kindred products. All monetary values were adjusted into 1970 dollars by the consumer price index. The t-values in parantheses are all significant at the 0.01 level.

Assuming that the net marginal cost of water equals \$0.35/1,000 gallons, two conclusions about industrial water demand were made: (1) the net marginal cost of water and normal sewer does effect the quantity of industrial water demanded; a 10 percent increase in the marginal price results in a decrease of around 7 percent in quantity demanded (elasticity = -0.70), and (2) the level of the surcharge affects the quantity of industrial water demanded; a 10 percent increase in the surcharge results in a decrease of around 6 percent in the quantity demanded (elasticity = -0.61).

Data Base Information:

Study Area Data

Location and water users: Industrial customers in 34 U.S. cities.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: decreasing block and sewer surcharge.
User sector: industrial.
Area character: urban.

Water Use Data

Maximum number of cases: 198 observations.
Type of measurement: secondary data ; utilities provided information on water consumption of industries city by city.
Measurement period: 1957-70.
Dependent variable: gallons of water per day per $1,000 value added in manufacturing.
Estimating technique: OLS regression.
Price variable specification: (1) net marginal price of water and normal sewer in $/1,000 gallons; (2) the surcharge in $/1,000 pounds of BOD.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: -0.70 for net marginal price; -0.61 for industrial waste.

16 Ethridge, Don E. 1970. An Economic Study of Municipal Sewer Surcharges on Industrial Wastes. Ph.D. Diss. North Carolina State University, Raleigh.

Abstract:

The major purpose of this paper is to evaluate the effect of municipal sewer surcharges on the quantity of waste discharged by firms into municipal sewer systems. However, the response of the marginal price of water and sewer plus an imposition of a surcharge on water demand is also evaluated.

The sample was limited to poultry processing firms located in cities that had been providing for and enforcing municipal sewer surcharges for more than five years. A total of 27 time-series and cross-sectional observations were obtained from five poultry processing firms.

Eight OLS regression models were estimated from the data and presented in the paper. The log-linear equation that was chosen as the most realistic for the demand of water is:

$$\log Q = -1.6933 - \underset{(0.47)}{0.1987}\,(P_{mt} + 0.5\,P_{ss}) - \underset{(2.00)}{0.0002}\,P_{w+s} + \underset{(2.78)}{0.3777}\,T$$

$R^2 = 0.55$ F = N.R. N = 23

Where: Q = million pounds of water per 1,000 birds processed per year; P_{mt} = sewer surcharge in cents per pound of BOD; P_{ss} = surcharge on suspended solids (ss) in cents per pound of SS; P_{w+s} = marginal price for water and sewer in cents per million pounds; and T = presence of automatic gizzard splitting is equal to one, zero otherwise. All coefficients are significant at the 0.05 probability level or better. The sample size equaled 23 because one sample firm was omitted.

Calculated elasticities equal -0.436 for the mean surcharge and -0.629 for the mean marginal price.

Data Base Information:

Study Area Data

Location and water users: 5 poultry-dressing plants in the U.S.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: not specified.
User sector: industrial.
Area character: urban.

Water Use Data

Maximum number of cases: 27 observations (pooled time-series/cross-sectional).
Type of measurement: secondary usage data from city governments plus mail survey of the firms.
Measurement period: not clearly specified: assume mid to late 1960s.
Dependent variable: million pounds of water per 1,000 birds processed annually.
Estimating technique: OLS regression.
Price variable specification: (1) marginal price of water and sewer in cents per million pounds; (2) sewer surcharge in cents per pound of BOD.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: -0.426 for average surcharge; -0.629 for mean marginal price.

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Flack, J. E. 1965. Water-Rights Transfers: An Engineering Approach. Ph.D. diss. Stanford University. Palo Alto, California.

Abstract:

This study used data for 54 Western cities to develop a spatial price-demand relationship for metered water deliveries. In order to compare the cross-sectional data, Flack notes that the price-demand relations for various cities must be on a similiar base. Therefore, the selected cities reported water use mainly on a distribution basis and the cities had similiar industrial and commercial water sales. Although some cities provided production data, the distribution data were given greater weights.

Delivered water on a per capita basis was computed for 54 Western cities. The data were obtained from the 1955 American Water Works Association survey data. A scatterplot of per capita use and monthly rates was presented. A trend line was fitted by observing the scatter of points. From the scatterplot and the fitted curve, elasticities for domestic water supplies were estimated. The table of elasticities is presented as:

Price cents/1,000 gallons	Demand	Elasticity
	Western cities	
15	213 gpcd	-1.0
25	134 gpcd	-0.61
35	113 gpcd	-0.32
45	108 gpcd	-0.12

Source: Flack 1965.

Therefore, water demand for the western cities were found to vary inversley with price.

Data Base Information:

Study Area Data

Location and water users: 54 Western cities.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: mixed rates due to multi-site data.
User sector: aggregate municipal.
Area character: urban.

Water Use Data

Maximum number of cases: 54 observations.
Type of measurement: secondary.
Measurement period: 1955.
Dependent variable: N.A.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: scatterplot with observed trend line.
Price variable specification: average price for all customers of a utility.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: -0.12 to -1.0 (average price).

18

Foster, Henry S., Jr. and Bruce R. Beattie. 1979. Urban Residential Demand for Water in the United States. Land Economics 55(1):43-58.

Abstract:

The purpose of this study was to develop a single equation econometric demand model for urban residential water demand that could be applied uniformly throughout the United States. The explanatory variables used in the multi-coefficient demand model are average water price, median household income, precipitation during growing season, and average number of residents per meter. The model utilizes price in exponential form and all other variables in power form so that price elasticity may be allowed to vary with price. Data on water quantity, price, and residents per meter for 218 cities in the United State were supplied from A Survey of Operating Data for Utilities in 1960 by the American Water Works Association. Income and climatological data were supplied by the 1960 Census of Population and Climatological Data for the United States, 1960-61, respectively.

A variation of the aggregate model was developed to test for regional and size-of-city differences. Regions were separated by factors such as drought potential, agricultural production patterns, manufacturing, and monthly precipitation. Using the F-test procedure, the hypothesis that demand is invariant among regions of the U.S. was rejected. However, the study did not reject the hypothesis that water demend is invariant to size-of-city criteria.

The estimated aggregate demand model using average price is

$$\text{Log } Q = -0.6035 - \underset{(10.71)}{0.1278\text{Pau}} + \underset{(4.69)}{0.4619\log I} - \underset{(6.79)}{0.1699\log F} + \underset{(3.69)}{0.4345\log H}$$

$R^2 = 0.545$ $\quad$ $F = 63.69$ $\quad$ df = 4,213

Where: Q = quantity of water demanded per meter (1,000 cubic feet per year); P_{as} = average water price (dollars per 1,000 cubic feet); I = median household income (dollars per year); F = precipitation (inches) during growing season; and H = average number of residents per meter. Values in parentheses are t-values. The F-statistic for the equation was significant at the .01 level as were all the coefficients using the t-test.

Price elasticity estimates from the regional models compared to previous regional studies compared very favorably with one exception. However, this exception may be due to a greater time lag between the two studies. The price elasticities, estimated at the means, range from -0.27 in Calumet City to -0.76 for Colorado Springs.

Data Base Information:

Study Area Data

Location and water users: 218 cities in the United States.
Mean summer temperature: Not applicable due to aggregation.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: not specified.
User sector: residential.
Area character: urban.

Water Use Data

Maximum number of cases: 218 observations.
Type of measurement: secondary, groups of users with dissimiliar characteristics.
Measurement period: 1960.
Dependent variable: quantity of water demanded per meter (1,000 cubic feet per year).
Summer season definition: not specified.
Winter season definition: not specified.
Price variable specification: average water price (dollars per 1,000 cubic feet).
Estimating technique: ordinary least square regression.
Special circumstances: none specified.

Minimum, maximum, and mean variable values:

Q = 4.76-49.80; 10.89 in 1,000 cubic feet/year.
P_{au} = 0.69-10.24; 3.67 $/1,000 cubic feet.
P_{au} = 0.09-1.37; 0.49 $/1,000 gallons.
I = $2,436-$22,177; $5,936.
F = 0.1-64.0; 23.13 inches.
H = 1.84-7.33; 4.29 persons per household.

Price elasticities: Great Bend = -0.67; Calumet City = -0.27; Colorado Springs = -0.76.

19 Fourt, Louis. 1958. "Forecasting the Urban Residential Demand for Water." Unpublished Paper. Department of Economics, University of Chicago.

Abstract:

Utilizing the 1955 American Water Works Association survey of operating utilities, Fourt selected a cross-section of 34 urban systems in the U.S. that had 100 percent metering. The 34 systems had provided data on water prices and usage. The log-linear regression equation that was estimated is:

$$\log Q = 5.812 - \underset{(5.22)}{0.386} \log P_{ms} - \underset{(5.29)}{0.037} \log X - \underset{(4.77)}{0.305} \log H$$

$R^2 = 0.683$ F = N.R.

Where: Q = quantity of residential water used per person per year (1,000 cubic feet); P_{ms} = marginal price per 1,000 cubic feet at 1,000 cubic feet per month ($); X = number of days of rainfall in June, July, and August (1955); and H = average number of persons per meter. The coefficients were found to be significant (population served was nonsignificant and was deleted from the equation). The regression equation produced a constant elasticity of -0.386 for residential water demand.

Data Base Information:

Study Area Data

Location and water users: 34 metropolitan systems in the U.S.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: varied due to multi-site data.
User sector: all residential.
Area character: urban.

Water Use Data

Maximum number of cases: 34 observations.
Type of measurement: secondary data from 1955 AWWA survey.
Measurement period: 1955.
Dependent variable: quantity of residential water used per person in 1,000's of cubic feet per year.
Summer season definition: June, July, August.
Winter season definition: not specified.
Estimating technique: regression.
Price variable specification: marginal price in dollars per 1,000 cubic feet per month.

Price elasticities: -0.386 (log with marginal price).

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Gallagher, D. R., and R. W. Robinson. 1977. Influence of Metering, Pricing Policies and Incentives on Water Use Efficiency, Technical Paper no. 19. Australian Water Resources Council. Canberra, A.C.T., Australia.

Abstract:

This monograph on water demand and pricing policy includes a report of two pricing experiments. In each case, cooperating households were presented with a hypothetical price on which to base their water use decisions. At the end of a week, they were told what water use had been, what the total cost would have been at the hypothetical price, and what the actual cost had been at the actual price. They were then told that a new price was to be "in effect" for the following week. The experiment was conducted during the winter of 1974 in Nowra, N.S.W., Australia; a similar experiment was conducted during the summer of 1974-75 in Wollongong, N.S.W., Australia. Water use data were obtained by daily readings of meters, some specially installed. Other data were obtained by interview and observation.

The following water use models were obtained:

(1) Nowra winter study

$$\ln Q = \underset{(13.97)}{7.906} + \underset{(3.27)}{4.131}\,A + \underset{(2.05)}{0.283}\,\ln H - \underset{(2.42)}{0.334}\,\ln T + \underset{(2.08)}{0.206}\,\ln U$$

$$- \underset{(2.03)}{0.242}\,\ln P_h + \underset{(1.93)}{0.133}\,\ln L - \underset{(4.88)}{0.200}\,\ln G - \underset{(5.79)}{0.712}\,\ln PB$$

$R^2 = 0.646$ [equation reported significant at 1 percent level]

Where: A = 1 for automatic washing machine, 0 otherwise; T = total number of taps/household; U = number of bathing or toilet facilities/household; L = number of clothes washing cycles/week/household; G = hours/week spent irrigating lawn and garden/household; PB = hours/week spent bathing/household. Weekly household water use (Q) is measured in Imperial gallons/week; hypothetical price (P_h) in Australian cents/100 Imperial gallons.

(2) Wollongong summer study

(a) Domestic (indoor) use

$$\ln Q = [\text{constant not reported}] - \underset{(1.96)}{0.5471}\,\ln I + \underset{(2.22)}{0.1201}\,\ln(P) + \underset{(5.80)}{0.609}\,NA$$

$$+ \underset{(4.95)}{0.683}\,NC + \underset{(3.39)}{0.8091}\,\ln WA - \underset{(2.85)}{0.575}\,\ln L$$

$R^2 = 0.428$ $F = 15.575$ d.f. = N.R.

$$\ln Q_c = [\text{constant not reported}] - \underset{(2.14)}{0.2651} \ln P_h + \underset{(1.92)}{0.111} \ln(P)$$

$$+ 0.358 \ln L + 2.29 \ln U$$

$R^2 = 0.288$ $F = 5.257$ d.f. = N.R.

Where: P = change in hypothetical price over previous week (Australian cents/100 Imperial gallons); NA = number of adults/household; NC = number of children/household; WA = hours/week spent bathing by adults/household; U = number of bathing or toilet facilities/household; L = number of clothes washing cycles/week/household; and G = hours/week spent irrigating lawn and garden/household. The second model has per capita water use (Q_c) as its dependent variable.

(b) Garden (outdoor) use

$$\ln Q = [\text{constant not reported}] + \underset{(2.18)}{0.974} \ln I + \underset{(2.81)}{3.384} \ln(tmp)$$

$$- \underset{(7.29)}{0.6631} \ln(prc)$$

$R^2 = 0.538$ $F = 18.217$ d.f. = N.R.

$$\ln Q_c = [\text{constant not reported}] + \underset{(1.95)}{2.205} \ln AAV + \underset{(3.06)}{3.5191} \ln(tmp)$$

$$- \underset{(7.36)}{0.6401} \ln(prc) - \underset{(3.98)}{3.1001} \ln U$$

$R^2 = 0.570$ $F = 14.452$ d.f. = N.R.

Where: (tmp) = average weekly temperature (celsius); (prc) = total weekly precipitation (mm); and AAV = property value (A$). Income (I) is measured by an index equal to annual household income (A$) divided by A$1,000, then rounded up to the next integer. Income in excess of A$12,000 are assigned an index value of 12.

The apparent price elasticity is -0.242 for the Nowra winter study. Price appeared in the Wollongong summer study of domestic (indoor) water use but not in the outdoor models. Since the domestic models include a first difference price term, the elasticity calculation requires knowledge of the average value of the last period price. These values are not supplied. The authors ignore the price differnece term, incorrectly reporting elasticity to be -0.2651 for the domestic per capita use model.

Interpretation of the results must consider the hypothetic nature of the data (responses to assumed, rather than actual prices, with no economic incentive present) and the very small size of the sample. The Nowra study is based on 14 households observed for each of six weeks; the Wollongong study used 12 households, observed for 12 weeks. Serial correlation is reported, but no details are provided. The authors describe the results as "an indicator only of what the residential water demand determinants may be." The author's state that the "data have limited reliability for direct policy purposes."

Data Base Information:

Study Area Data

Location and water users:
(1) Nowra, N.S.W., Australia; 14 single-family residential households;
(2) Wollongong, N.S.W., Australia; 12 single-family residential households.

Mean summer temperature: N.R.
Mean summer precipitation: N.R.
Mean summer evapotranspiration: N.R.
Mean summer moisture deficit: N.R.
Water rates: zero marginal price for use up to "typical use" allowance; uniform price for all use in excess of allowance.
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: 84 in Nowra; 144 in Wollongong.
Type of measurement: primary.
Measurement period: Nowra--June-July 1974. Wollongong--N.R.; apparently November 1974-February 1975.
Dependent variable: Nowra--weekly household water use; Wollongong--weekly household indoor water use; weekly household per capita indoor water use; weekly household outdoor water use; and weekly household per capita outdoor water use.
Summer season definition: November-February.
Winter season definition: May-August.
Estimating technique: ordinary least squares regression.
Price variable specification: hypothetical marginal price.
Special circumstances: Nowra--survey followed year of greater than normal precipitation, local flooding.

Minimum, maximum, and mean variable values: no values reported.

Price elasticities: Nowra--winter household water use: -0.242. Not available for Wollongong.

21 Gardner, B. D. and S. H. Schick. 1964. Factors Affecting Urban Household Water in Northern Utah. Agricultural Experiment Station. Bulletin no. 449. Utah State Univerity. Logan.

Abstract:

The purpose of this study is to explain the variation in water consumption of average households among 43 water systems in Northern Utah in 1962. The municipal utilities provided data on aggregate water sales to all consumers. However, in the area 90 percent of industrial water is self-supplied, and almost all the communities have separate commercial districts. Therefore, the authors assume that their estimates approximate household water use with a slight upward bias. To eliminate the the effect of apartment houses with one connection, the dependent variable is measured on a per capita base.

In the original model estimated by Gardner and Schick the following explanatory variables were used: the weighted average price of the municipality per 1,000 gallons (P_{au}); median per capita income for 1960 (I); median home value per capita in 1960 (Y); lot area per capita in square feet (L); percent of homes with complete plumbing (X); average monthly precipitation measured in inches from May through October for 1962 (F); and average maximum daily temperatures in degrees F from May through October for 1962 (T). The estimated linear equation from ordinary least squares regression is:

$$(1)\ Q = 878.93 - \underset{(2.99)}{1042.65\, P_{au}} - \underset{(1.05)}{0.1852\, I} + \underset{(0.67)}{0.0330\, Y} + \underset{(2.88)}{0.0357\, L} + \underset{(3.81)}{849.03\, X}$$

$$+ \underset{(1.34)}{301.58\, F} + \underset{(0.13)}{2.23\, T}$$

$R^2 = 0.55$ Df = 35 F = N.R.

The values in parantheses are t-statistics. Only three variables were significant at the 0.05 level: plumbing, price, and lot size. Price elasticity at the means is -0.67. Income and precipitation had the opposite expected sign. The plumbing variable was observed to collinear with lot size. Therefore, the model was reestimated using only lot size and price. A logarithmic transformation was used to account for possible nonlinearity of the variables. The equation of best fit is estimated as:

$$(2)\ \text{Log}\ Q = 5.9504 - \underset{(11.70)}{0.7662 \log P_{au}} + \underset{(2.15)}{0.1506\ \text{Log}\ L}$$

$R^2 = 0.83$ Df = 40 F = N.R.

Both variables are significant at the 0.05 level. The price elasticity from the logarithmic equation is -0.77.

Data Base Information:

Study Area Data

Location and water users: 43 Northern Utah water systems.
Mean summer temperature: 65 degrees F.
Mean summer precipitation: 1-3 inches.
Mean summer evapotranspiration: 15-17 inches.
Mean summer moisture deficit: 14.4-15.2 inches.
Water rates: varied rates due to multi-site data; basically the municipality used either a fixed surcharge or a block rate.
User sector: aggregate municipal; however, commercial and industrial sectors are believed to be small.
Area character: urban.

Water Use Data

Maximum number of cases: 43 observations.
Type of measurement: aggregate water sales from municipality.
Measurement period: 1962.
Dependent variable: average daily use (divide gallons per capita annual consumption by 365).
Summer season definition: May-October.
Winter season definition: November-April.
Estimating technique: OLS multiple regression.
Price variable specification: average price for all customers of the utility ($/1,000 gallons).

Minimum, maximum, and mean variable values:

Q = 78-1,412; 245.02 gallons/capita/day.
P_{au} = 0.013-0.477; 0.157 $/1,000 gallons.
I = 1,074 - 1,877; 1,408 $/capita.
Y = 24.83 - 5,000; 3,426 $/capita.
L = 1,096 - 13,557; 4,460.1 square feet/capita.
X = 74 - 100; 94.28 percent.
F = 0.65 - 1.11; 0.996 inches/month.
T = 77.2 - 82.8; 80.50 degrees F.

Price elasticities: -0.77 (double-logarithmic), -0.67 (linear).

22 Gardner, Richard L. 1977. An Analysis of Residential Water Demand and Water Rates in Minnesota. Water Resources Research Center. Bulletin 96. University of Minnesota. Minneapolis.

Abstract:

The purpose of this bulletin was to examine the price elasticity of demand for residential water in Minnesota along with policy implications for rate making. The author determined a water demand function based on data from water sales, rate structures, and a breakdown into demand sectors. The data were obtained through a mail survey of 650 Minnesota municipalities (population range of 2,500 to 25,000) having a public water system and from the 1970 population census.

The variables used in the ordinary least squares multiple regression model are as follows: (1) daily per capita residential water consumption (dependent variable); (2) population served; (3) four alternate price measures; (4) per capita income; (5) number of persons per residence; (6) education level; (7) proportion of rented units; (8) number of bathrooms; (9) average minimum water deficiency (evapotranspiration less precipitation); and (10) proportion of youths (less than 18 years old).

From a sample of 75 towns, it was found that only variables (2), (3), (4), and (10) helped to explain variance in water consumption. The four alternate price measures tested were marginal price of water to the customer, marginal price of water and sewer in winter, marginal price of water and sewer in summer, and average price of water and sewer in the winter. It was found that the marginal price of water and sewer in winter was the most significant. The significance of this price variable may be due to the fact that many of the towns base summer sewer charges on the winter water consumption.

The estimated equation is presented in both linear and double-log forms. The equations are as follows:

(1) Linear

$$\underset{(2.51)}{Q = 50.82} - \underset{(10.0)}{.0043S} - \underset{(2.54)}{21.94P_{ms}} + \underset{(1.82)}{.008I} + \underset{(3.48)}{2.19X}$$

$$R^2 = 0.28 \quad F = 6.93 \quad d.f. = 4,70$$

(2) Double-log

$$\text{Log } Q = \underset{(13.89)}{4.86} - \underset{(5.10)}{0.26 \text{ Log}S} \underset{(2.33)}{-0.1535 \text{ Log } P_{ms}} + \underset{(4.5)}{0.54 \text{ Log}X}$$

$$R^2 = 0.36 \quad F = 13.1 \quad d.f. = 3,71$$

Where: Q = daily per capita water consumption, S = population served, P_{ms} = marginal price of water and sewer in winter, I = per capita income (deleted in log model), and X = proportion of youths (under 18). In the linear model all variables are significant at less than 0.02 level except for income which is significant at the 0.076 level. In the double-log model all variables are significant at less than the 0.025 level. The F-value of both forms are significant at less than the 0.001 level. Price elasticities were found to be in the range of -0.15 to -0.24.

The explanatory power (R^2 values) of the equations was rather low. The use of averages for communities may have decreased the power of the variables.

Data Base Information:

Study Area Data

Location and water users: 75 (medium sized) cities in Minnesota.
Mean summer temperature: 60-70 degrees F.
Mean summer precipitation: 10-14 inches.
Mean summer evapotranspiration: 13-17 inches.
Mean summer moisture deficit: 7-9 inches.
Water rates: mixed rates due to multi-site data (mostly declining block).
User sector: residential.
Area character: cities of 2,500 to 25,000 in population were included in the survey.

Water Use Data

Maximum number of cases: 75 observations.
Type of measurement: mail survey of the utilities.
Measurement period: 1975.
Dependent variable: daily per capita residential water consumption.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: ordinary least squares regression.
Price variable specification: marginal cost of water and sewer in the winter ($/1,000 gallons).

Minimum, maximum, and mean variable values:

Q = 39.4-228.0, 78.7 gallons/capita/day.
P = $0.15-$1.95, $0.85
S = 84-23,253; 7,517 persons.
I = $2,330-$5,983; $3,641.
X = 11.8-54.1; 22.8 percent.

Price elasticity: -0.24 (linear); -0.15 (double-log).

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23 Gibbs, Kenneth C. 1978. Price Variable in Residential Urban Water Demand Models. Water Resources Research 14(1):15-18

Abstract:

The author's purpose was to assess the difference in price elasticities obtained when using average or marginal price in multiple coefficient water demand models. Two equations are estimated for 355 residential customers in Miami, Florida.

The estimated demand equation with marginal price is:

$$(1)\ \ln Q = 3.12 - \underset{(10.88)}{1.85P_{mc}} - \underset{(27.57)}{1.93Z_0} + \underset{(13.33)}{0.000040I} - \underset{(7.00)}{0.14H} + \underset{(6.18)}{7.79X_1} +$$

$$\underset{(2.00)}{0.06Z_1} + \underset{(1.0)}{0.03Z_2} - \underset{(1.0)}{0.03Z_3}$$

$$R^2 = 0.60 \qquad F = 267.24 \qquad d.f. = 1403$$

Where: Q = quarterly household water consumption in 1,000 gallons; Z_0 = dummy variable for zero marginal price; H = persons per household; X_1 = percantage of homes with hot water heater; and Z_1, Z_2, Z_3 = seasonal dummy variables. Price elasticity, at the mean marginal price of \$0.28/1000 gallons, is estimated to be -0.51.

The estimated demand equation with average price as explanatory variable is:

$$(2)\ \ln Q = 2.02 - \underset{(35.67)}{1.07P_{ac}} + \underset{(16.0)}{0.000064I} + \underset{(14.5)}{0.29H} + \underset{(2.72)}{3.92X_1} + \underset{(2.0)}{0.08Z_1} -$$

$$\underset{(0.50)}{0.02Z_2} - \underset{(0.50)}{0.02Z_3}$$

$$R^2 = 0.46 \qquad F = 176.37 \qquad d.f. = 1404$$

Where: P_{ac} is the average price per 1,000 gallons. Price elasticity, at the mean average price of \$0.58/1,000 gallons, was estimated to be -0.62.

All regression coefficients are statistically different from zero at 1 percent probability level except those for Z_2 and Z_3 in the first equation and the second equation.

Data Base Information:

Note: This study is also published in Andrews and Gibbs, Southern Journal of Agricultural Economics 7(1):125-29.

Study Area Data

Location and water users: Miami SMSA, Florida, 355 individual households served by about 10 water companies.
Mean summer temperature: 82 degrees F.
Mean summer precipitation: 28 inches.

Mean summer evapotranspiration: 19 inches.
Mean summer moisture deficit: 2.2 inches.
Water rates: varying (decreasing block, some uniform, service charge, minimum charge).
User sector: residential (probably single-family).
Area character: suburban.

Water Use Data

Maximum number of cases: 1,412.
Type of measurement: secondary, quarterly water bills for individual households.
Measurement period: February 1973–January 1974.
Dependent variable: quarterly water consumption in 1,000 gallons per household (meter).
Season definition: dummy variables used to distinguish the four periods: February-April; May-July; August-October; November-January.
Estimating technique: ordinary least squares.
Price variable specification:
(1) nominal marginal price for individual households in \$/1,000 gallons; (2) nominal average price for individual households in \$/1,000 gallons.
Both price variable specifications poorly reported.

Minimum, maximum, and mean variable values:

Q = 1-336, 32 in 1,000 gallons/quarter.
Pmc = \$0-\$0.60; \$0.28/1,000 gallons.
Pac = \$0.20-\$7.50; \$0.58/1,000 gallons.
I = \$6,960-\$21,090; \$12,830/household.
H = 2.04-4.60; 3.01 persons/household.
X_1 = 0-4; 0.9 percent of households with hot water heat in each service area.

Price elasticities at mean variable values: -0.51 (marginal); -0.62 (average).

24

Gottlieb, M. 1963. Urban Domestic Demand for Water: A Kansas Case Study. Land Economics 39(2):204-10.

Abstract:

This paper presents an economic analysis of municipal water demand based on aggregated water use data. The author's purpose was to isolate the effect of price and income on water use in small Kansas towns during the 1950s. The analysis is based on area-wide averages, total consumption divided by either population or the number of customers, and community-wide average household income. The price of water was derived by dividing total water revenue by the total amount of water used.

The author uses a double-log functional form to estimate consumption:

$$\text{Log } Q = \log a + b \log I + c \log P$$

Where: Q = water use; I = average household income (\$); and P_{au} = average price in cents per 1,000 gallons. From a table that presents the results of the multiple regression analysis, the following functions were produced:

(1) 1952 data from 19 water systems (measured in 1,000 gallons per customer per year).

$$\text{Log } Q = \log a + 0.45 \log I - 1.24 \log P_{au} \qquad R^2 = 0.69$$

(2) 1957 data from 24 water systems (measured in 1,000 gallons per customer per year).

$$\text{Log } Q = \log a + 0.58 \log I - 0.68 \log P_{au} \qquad R^2 = 0.72$$

(3) 1957 data from 24 water systems (measured in 1,000 gallons per capita per year).)

$$\text{Log } Q = \log a + 0.29 \log I - 0.66 \log P_{au} \qquad R^2 = 0.69$$

Therefore, the results of cross-sectional multiple regressions on per customer water consumption showed price elasticities of -1.24 and -0.68 for the years 1952 and 1957, respectively. The per capita water consumption model for 1957 estimated a price elasticity of -0.66, which is similiar to the per customer equation for the same time period. However, no significance tests were reported for the regression coefficients.

Two measures of consumption were also correlated, i.e., per capita versus per customer consumption. For 24 cities in 1957 and 20 cities in 1952 the author has obtained the estimating equations: $Q = 8.21211 + .25165\ X$ ($R^2 = 0.83$), and $Q = -1.056 + 0.3165\ X$ ($R^2 = 0.93$), respectively, where Q is per capita consumption and X is consumption per connection.

Data Base Information:

Study Area Data

Location and water users: waterworks systems in Kansas.
Mean summer temperature: 74-77 degrees F.
Mean summer precipitation: 8-12 inches.
Mean summer evapotranspiration: 17-20 inches.
Mean summer moisture deficit: 9.8-15.2 inches.
Water rates: mixed rates in multi-site data.
User sector: aggregate municipal.
Area character: small towns.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: secondary.
Measurement period: 1952-57.
Dependent variable: consumption in 1,000 gallons annually.
Estimating technique: multiple regression.
Price variable specification: average price for all customers of utility.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: -0.66 to -1.24 (log with average price).

25 Grebstein, C. R., and B. C. Field. 1979. Substituting for Water Inputs in U.S. Manufacturing. Water Resources Research 15(2):228-32.

Abstract:
This study describes an attempt to estimate the long-run elasticities of substitution among capital, labor, and water, based on cross-sectional state data for all SIC two-digit U.S. industries for 1973. The authors compiled a data set including: (1) 1973 water withdrawals in each SIC category by states reported in the 1972 census of manufacturers; (2) labor and capital inputs; and (3) two different series of water prices by states derived from the American Water Works Association surveys and from of Montanari and Mattern (JAWWA 67 [1975]:251-54).

The estimated of elasticities are obtained by using a transcendental logarithmic cost function in lieu of the traditional production function. The trans-log function was used to formulate three input demand functions:

$$M_K = P_K(K/C) = a_K + b_{KK} \ln P_K + b_{KL} \ln P_L + b_{KW} \ln P_W$$
$$M_L = P_L(L/C) = a_L + b_{KK} \ln P_K + b_{LL} \ln P_L + b_{LW} \ln P_W$$
$$M_W = P_W(W/C) = a_W + b_{KK} \ln P_K + b_{LW} \ln P_L + b_{WW} \ln P_W$$

Where: K, L, and W refer to inputs of capital, labor, and water, respectively; M_K, M_L, and M_W are their cost shares, and P_K, P_L, P_W are their prices. The system of the first two equations was used to estimate the a and b coefficients using the simultaneous estimating technique based on generalized least squares developed by Zelner (1962).

The "own" and "cross-price" elasticities of input demand reported in the article were calculated using definitions derived by Berndt and Wood (Rev. Econ. Statist. 57 [1975]:376-84]):

$$n_{ii} = (b_{ii} + M_i^2 - M_i)/M_i \quad \text{where } i = K,L,W$$

and

$$n_{ij} = (b_{ij} + M_iM_j)/M_i \quad \text{where } ij = K,L,W$$

Where: n_{ij} represents cross-price elasticity of input demand which in case of $i = K$ and $j = W$, measures the percentage change in the quantity of the capital input resulting from a 1 percent change in the price of the water input, while output is held constant. The "own" elasticities of water demand, n_{WW}, calculated at mean input cost share of water, M_W, in the sample were -0.326 for the AWWA prices and -0.801 for the Montanari and Mattern price series, with the former estimate being not different from zero at conventional significance levels.

Cross-price elasticities between water and the labor were positive (ranging from $n_{LW} = 0.036$ to $n_{WL} = 2.383$), while those between water and capital were consistently negative ($n_{CW} = -0.130$ to $n_{WC} = -2.051$). These signs of cross-price elasticities are interpreted by the authors to indicate that water and labor inputs are substitutes, while water and capital are complements. The latter means that more capital intensive production processes are accompanied by an increase in water use coefficients. However, the authors suggest some caution in interpretation of this and other conclusions because of many weak assumptions and imperfect (i.e., highly aggregated) data used in their analysis.

Data Base Information:

Study Area Data

Location and water users: all SIC two-digit industries in 45 states of the U.S.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: mixed rates.
User sector: industrial.
Area character: not specified.

Water Use Data

Maximum number of cases: not specified (number of two-digit industrial categories times 45).
Type of measurement: not specified.
Measurement period: 1973.
Estimating technique: generalized least squares.
Water price range: \$71 to \$306 per million gallons; other variable values were not specified.
Price elasticities: -0.326 and -0.801.

26

Grima, Angelo P. 1972. Residential Water Demand: Alternative Choices for Management. University of Toronto Press.

Abstract:

This book presents an extensive study, both theoretical and empirical, of residential water demand in the Toronto metropolitan area. The cross-sectional water use data used in this study are based on 91 individual observations from metered single unit households for 1967. These water use data were averaged over a year, the summer period, and the winter period, thus producing average water use in gallons per day in a dwelling unit over each period.

The logarithmic equations using only the significant variables are presented below.

(1) Average annual

$$\log Q_a = 2.78 + \underset{(4.43)}{0.56} \log Y + \underset{(7.26)}{0.59} \log H - \underset{(-4.14)}{0.93} \log P_{mc} - \underset{(-2.26)}{0.31} \log B$$

$R^2 = 0.56$ S.E. = 0.15 F = 27.5 DF = 86

(2) Average summer

$$\log Q_s = 3.24 + \underset{(3.80)}{0.51} \log Y + \underset{(7.29)}{0.63} \log H - \underset{(-4.50)}{1.07} \log P_{mc} - \underset{(-2.40)}{0.35} \log B$$

$R^2 = 0.55$ S.E. = 0.16 F = 26.45 DF = 86

(3) Average winter

$$\log Q_w = 2.45 + \underset{(3.37)}{0.48} \log \quad + \underset{(6.82)}{0.62} \log H - \underset{(-3.03)}{0.75} \log P_{mc} - \underset{(-1.56)}{0.24} \log B$$

$R^2 = 0.49$ S.E. = 0.16 F = 20.38 DF = 86

Where: Q_a, Q_s, Q_w are measured in gallons per day per dwelling unit; Y = is assessed home value in hundreds of dollars; H = persons per household; P_{mc} = marginal price in cents per 1,000 gallons; and B = the fixed bill for one billing period in cents. The signs and values of the regression coefficients are as expected, and the residuals were examined for departures from normality and lack of homogeneity. With the exception of the coefficient for B in the winter model, all coefficients are significant at the 0.01 probability level. The F-ratios indicate that the three equations are significant at the 0.01 level.

The elasticities of demand with respect to price are found to be -0.93, -1.07, and -0.75 for average annual, summer, and winter water use, respectively.

Data Base Information:

Study Area Data

Location and water users: 91 residential households in the Toronto metropolitan area.
Mean summer temperature: 60-65 degrees F.
Mean summer precipitation: 8-10 inches.
Mean summer evapotranspiration: 13-14 inches.
Mean summer moisture deficit: 7-9 inches.
Water rates: uniform.
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: 91 observations.
Type of measurement: secondary data of individual users from the water utilities.
Measurement period: 1967.
Dependent variable: (1) average annual water use (gallons/day/dwelsing unit. (2) average summer use (same units). (3) average winter use (same units).
Summer season definition: May-August.
Winter season definition: November-March.
Estimating technique: OLS multiple regression.
Price variable specification: marginal price of each user (cents/1,000 gallons).

Minimum, maximum, and mean variable values:

Q_a = mean: 142.919 gallons/day/dwelling; Standard deviation (std. dev.) = 67.91.
Q_s = mean: 158.038 gallons/day/dwelling; Std. dev. = 81.32.
Q_w = mean: 127.764 gallons/day/dwelling; Std. dev. = 61.43.
P_{mc} = 30-80; 45 cents/1,000 gallons.
Y = mean: 195.251 (100 dollars); Std. dev. = 64.166.
H= mean: 3.989 persons per household; Std. dev. = 1.69.
B = mean: 316.980 cents/billing period; Std. dev. = 121.480.

Price elasticities: average annual = -0.93; average summer = -1.07; and average winter = -0.75 (all log with marginal price).

27 Grunewald, O. C., C. T. Haan, David L. Debertin, and D. I. Carey. 1976. Rural Residential Water Demand: An Econometic and Simulation Analysis. Water Resources Bulletin 12(5):951-61.

Abstract:

This paper examines residential water use in 150 rural areas in Kentucky, specifically those provided with public water supply by means of connections to nearby urban areas. The purpose of the study was to demonstrate the application of econometric demand functions to the determination of optimal pricing policies and reservoir design criteria and to show the interaction between design criteria and optimal rate structure.

The data collected for the 150 rural residential areas varied in size from 15 to 2,064 customers. Water use data (Q) and prices (P_{ac}) in 1972 were obtained from the Kentucky Public Service Commission. Mean income (I), mean housing unit value (Y), and mean number of persons per household (H) were obtained from 1970 census reports. Summer evaporation (X) data (1972) were collected from Climatological Data-Kentucky.

A multiple regression analysis was performed on the cross-sectional data, using both linear and log-linear models. Results of the linear demand function using the above variables estimated R^2 to be 0.15, price to be the only significant variable (0.01 level), and standard errors for the coefficients to be generally large. The log-linear demand model estimates that $R^2 = 0.68$. P_{ac} was significant at the 0.01 level and X was significant at the 0.10 level. However, the coeffient for income had the wrong sign which may have been due to high correlation with house value. Deleting all variables except for P_{ac} and I, the resulting regression is:

$$(1)\ \log Q = \log (63.43) - \underset{(18.40)}{0.92} \log P_{au} + \underset{(1.38)}{0.18} \log I$$

Where: $R^2 = 0.67$ and P and I are statistically significant at the 0.01 level and 0.10 level, respectively. The authors conclude that the model which best represents rural residential water use in Kentucky is the following:

$$(2)\ \log Q = \log (90.92) - \underset{(18.4)}{0.92} \log P_{au}$$

The authors further conclude that the elasticity of residential water consumption is negative (-0.92), the demand function is hyperbolic in shape, the other factors had little effect on water use, and pricing policies may be used to reduce capacity requirements. Elasticity estimates may have been biased because of the use of average price where rate structures are predominantly declining block.

Data Base Information:

Study Area Data

Location and water users: 150 rural water districts in Kentucky (varied in size from 15 to 2,064 customers).
Mean summer temperature: 72-76 degrees F.
Mean summer precipitation: 8-12 inches.
Mean summer evapotranspiration: 14-18 inches.
Mean summer moisture deficit: 9.2-10.8 inches.
Water rates: mixed rates due to multi-site data (mostly declining block).
User sector: residential.
Area character: rural.

Water Use Data

Maximum number of cases: 150 observations.
Type of measurement: secondary data from Kentucky Public Service Commission.
Measurement period: 1972; (1970 census data).
Dependent variable: quantity of water used per year per dwelling unit (1000 gallons).
Summer season definition: June-September.
Winter season definition: not specified.
Estimating technique: multiple regression.
Price variable specification: average price of all customers of utility.

Minimum, maximum, and mean variable values:

Q = 2.87-521.48, 56.39 in 1,000 gallons/year/household; Standard deviation (Std. dev.) = 50.71.
P_{au} = 0.27 - 14.49 2.27 in $/1,000 gallons; Std. dev. = 1.48.
I = 3.52 - 11.28, 6.59 in $1,000; Std. dev. = 1.51.

Price elasticities: -0.92 (log with average price).

28

Hanke, Steve H. 1970. **Demand for Water under Dynamic Conditions.** Water Resources Research 6(5):1253-61.

Abstract

The purpose of Hanke's study was to evalute the demand side of the residential water market. This article examines the effects of the change from flat rates to commodity (metered) changes for single-family dwelling units in Boulder, Colorado, using time-series data for the years 1955-68. In 1961, the Boulder water utility installed meters and enacted an incremental commodity charge of 35 cents per thousand gallons. The empirical data from the Boulder utility had some shortcomings. The water use data for the flat rate period, 1955-61, were available only on an aggregate basis for the entire city of Boulder. However, for this time period commercial and industrial usages were subtracted, yielding total residential use. The data for the years 1962-68 were available as aggregate data by residential meter routes.

In this study, Hanke distinguished between sprinkling and domestic use. To evaluate the relationship between ideal and actual sprinkling use a single equation model with dummy variables was used. The model supposes that actual sprinkling and ideal sprinkling are linearly related. The basic regression used is:

$$q_t = y_1 + y_2X_2 + B_1Q_t + B_2Z$$

Where: q_t = actual sprinkling consumption; Q_t = ideal sprinkling consumption; X_2 is the dummy variable such that $X_2 = 0$ during flat rate months and $Z = X_2 = 1$ during metered months; $Z = X_2Q_t$; and y_1, y_2 are intercepts and B_1, B_2 are slope coefficients for flat rates and metered rates, repectively. This equation is empirically used to evaluate sprinkling on various routes. One of the eight equations presented representing two meter routes (73,75) is:

$$q_t = 8.26 - \underset{(5.10)}{7.09X_2} + \underset{(10.0)}{0.60Q_t} - \underset{(1.3)}{0.13Z}$$

$$R^2 = 0.69 \qquad F = 76.0$$

The eight equations presented R^2 values from 0.61 to 0.69 and F values from 46.65 to 76.00. All the intercepts and B_1 coefficients were significant at the 0.01 level. However, all the B_2 coefficients were insignificant, and therefore it was assumed that these slope coefficients remained the same as the flat rate coeffients. The empirical results of the study found that (1) "sprinkling demands were reduced by the introduction of meters, with actual sprinkling being greater than the calculated ideal under flat rates and less than ideal under metered rates; (2) sprinkling use not only declined with the introduction of meters but subsequently continued to decline."

The time-series data were also used to evaluate domestic (in-house) demands. Although no models or statistical data were presented, Hanke found that "domestic demands (in-house) were reduced 36 percent after meter installation and that domestic demands stabilized at these lower levels."

Data Base Information:

Study Area Data

Location and water users: Boulder, Colorado; 3,086 customers on the 14 residential metered routes.
Mean summer temperature: 65 degrees F.
Mean summer precipitation: 7 inches.
Mean summer evapotranspiration: 14 inches.
Mean summer moisture deficit: 9.8 inches.
Water rates: flat rate to uniform (35 cents per 1,000 gallons).
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: not specified.
Type of measurement: aggregate water sales.
Measurement period: flat rate: 1955-61; metered rate: 1962-68.
Dependent variable: in sprinkling demand equation: q = actual sprinkling consumption; unspecified for domestic demands.
Summer season definition: not specified.
Winter season definition: not specified.
Price variable specification: X_2 is a dummy variable where $X_2 = 0$ during flat rate months and $X_2 = 1$ during metered months.
Estimating technique: multiple regression.
Special circumstances: change from flat rates to metered rates.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticity: not reported.

29

Hanke, Steve H., and Lennart de Mare. 1982. Residential Water Demand: A Pooled Time Series, Cross Section Study of Malmo, Sweden. Water Resources Bulletin 18(4):621-25.

Abstract:

Using pooled time-series and cross-sectional data for 69 single-family houses in Malmo, Sweden, this study calculated an ordinary least squares regression model. The time-series data start with the last quarter of 1971 through the first quarter of 1972 and end with the second and third quarters of 1978 giving 14 semiannual periods. Secondary data were collected from various sources: usage data were collected from semiannual, metered water records; income data from tax records; house occupancy and rainfall data from city records. The linear demand model is presented as:

$$Q = 64.7 + \underset{(3.26)}{0.00017\ I} + \underset{(2.98)}{4.76\ X_1} + \underset{(3.09)}{3.92\ X_2} - \underset{(3.12)}{0.406\ F}$$

$$+ \underset{(11.54)}{29.03\ X_3} - \underset{(1.99)}{6.42\ P_{mc}}$$

$$R^2 = 0.259 \qquad F = \text{N.R.} \qquad N = 959$$

Where: Q = quanity of metered water used per house, per semiannual period (M^3); I = real gross income per house, in Swedish crowns per period; X_1 = number of adults per house per semiannual period; X_2 = number of children per house per semiannual period; F = rainfall per semiannual period/6 (in millimeters); X_3 is a dummy variable where $X_3 = 1$ for houses built from 1968-69 and 0 when built from 1936-46; P_{mc} = real price in Swedish crowns per M^3 of water per semiannual period. The real price includes all water and sewer commodity charges. The price of water is the real marginal price per M^3; a value that remains constant across houses within a given billing period, regardless of the quantity of water that each house uses. Price and income are adjusted using the Swedish Consumer Price Index. Numbers in parentheses are t-values; all variables are statistically significant at the 0.05 probability level.

The equation passed tests for multicollinearity, serial correlation (D-W), and heteroskedasticity. In reference to the low R^2 value, the authors state that "it is important to note that our pooled data are dominated by the cross-section data. Hence, the value of the R^2 is satisfactory for pooled analysis because of large variation across individual units of cross-section observation." The price elasticity calculated at the means is estimated at -0.15.

Data Base Information:

Study Area Data

Location and water users: 69 single-family residences in Malmo, Sweden.
Mean summer temperature: not reported.
Mean summer precipitation: not reported.
Mean summer evapotranspiration: not reported.
Mean summer moisture deficit: not reported.
Water rates: uniform.
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: 966 observations (actual data yield 959).
Type of measurement: secondary data from semiannual metered water use records.
Measurement period: fourth quarter 1971--third quarter 1978: 14 semiannual periods.
Dependent variable: quantity of metered water used per house, per semiannual period, in cubic meters (M^3).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: ordinary least squares regression.
Price variable specification: real marginal price per M^3.

Minimum, maximum, and mean variable values:

Q = mean: 75.21 M^3/house/semi-annual period, Standard deviation (Std. dev.) = 39.29.
I = mean: 49,497 Swedish crowns/house/period; Std. dev. = 21,781.
X_1 = mean: 2.05/house/period; Std. dev. = 0.75.
X_2 = mean: 0.93/house/period; Std. dev. = 1.04
F = mean: 39.13 millimeters (mm)/semiannual period/6. Std dev. = 7.78.
X_3 mean: 0.54; Std. dev. = 0.50.
P_{mc} = mean: 1.73 Swedish crowns/M^3/period; Std. dev. = 0.32.

Price elasticities: -0.15 (at the mean).

30

Hansen, Roger D., and Rangesan Narayanan. 1981. A Monthly Time Series Model of Municipal Water Demand. Water Resources Bulletin 17(4):578-85.

Abstract:

This article presents a multivariate time-series model that was designed to examine monthly variations in municipal water demand. The authors utilized data from the Salt Lake City Water Department (SLCWD) for the years 1961-77. The double-log model was developed from the 1961-74 data; and the following years were used to compare with an *ex post* forecast. The data were supplied in aggregate form, however, it was noted that "commercial and industrial water use represent approximately 16 and 6 percent of total usage, respectively."

Utilizing ordinary least squares (OLS) regression, several models were developed. Each model was subjected to evaluation with the t-test for significance, the d-statistic for serial correlation, and for twelfth-order autocorrelation. The double-log model that was chosen as the equation of best fit is as follows:

$$\text{Log } Q = \text{Log } \underset{(5.656)}{-2.62} - \underset{(7.862)}{0.06} \log F_g + \underset{(19.884)}{1.56} \log T_g - \underset{(-6.234)}{0.47} \log P_{au} +$$

$$\underset{(5.303)}{0.67} \log X_d + \underset{(27.941)}{7.26} \log Z_n$$

$R^2 = 0.97$ F = N.R. d.f. = N.R. D.W. = 2.095

Where: Q = water usage in gallons per connection per day (gkd); F_g = total rainfall during growing season (April-October) in inches; T_g = average temperature during growing season (°F); P_{au} = price in dollars per 100 cubic feet; X_d = percentage of daylight hours during growing season; and Z_n = nongrowing season dummy variable. Values in parentheses are t-statistics. The estimated price elasticity was -0.469, which compared favorably to other area studies.

Using the calculated model, an *ex post* forecast was made for the years 1975-77. With a 95 percent confidence interval, actual and predicted values were visually compared. The model correctly predicted seasonal usage except for a discrepancy in 1977. The discrepancy may have been caused by the extremely dry 1976-77 winter and voluntary use restrictions during that time.

Data Base Information:

Study Area Data

Location and water users: Salt Lake City, Utah, water department customers.
Mean summer temperature: 65 degrees F.
Mean summer precipitation: 3 inches.
Mean summer evapotranspiration: 16 inches.
Mean summer moisture deficit: 14.2 inches.

Water rates: uniform charge with seperate minimum service charge.
User sector: aggregate municipal.
Area character: urban, suburban.

Water Use Data

Maximum number of cases: 168 observations (14 years x 12 months).
Type of measurement: aggregate water sales.
Measurement period: 1961-77.
Dependent variable: water usage in gallons per connection day (gkd).
Summer season definition: not specified.
Winter season definition: not specified.
Price variable specification: average price for all customers in utility.
Estimating technique: ordinary least squares regression.
Special circumstances: very dry conditions during winter 1976-77 and summer 1977; voluntary water use restrictions during summer 1977.

Minimum, maximum, and mean variable values: No variable values reported

Price elasticity: -0.469 (log with average price).

31

Hittman Associates, Inc. 1970. Price, Demand, Costs, and Revenue in Urban Water Utilities. Columbia, Maryland. NTIS PB 195 929.

Abstract:

This report is a study of the municipal water industry, based on data collected from 46 urban water utilities which serve more than 10,000 in population in 1960. The primary purpose of this study was to develop improved rate-making policies for local utilities that would take account of effects of these policies, including relationships between price, demand, cost, and revenue. Data were obtained from various sources: the 1960 American Water Works survey, census reports, weather bureau reports, mail questionnaire, and telephone contacts. Prices for 1960 were adjusted using a regional price index to minimize differences in price because of geographic area.

Data on residential demand were obtained for 27 cities and were converted to average day gallons per residential connection (Q). The explanatory variables used are (1) residential marginal price in dollars per 1,000 gallons (Pms); (2) moisture deficit in inches (M); and (3) persons per connection (H). The following model is estimated with all values significant at the 0.05 probability level.

$$\log Q = \log 0.0001964 - \underset{(3.35)}{0.4387} \log P_{ms} + \underset{(7.10)}{0.6324} \log M + \underset{(2.05)}{0.4076} \log H$$

$R^2 = 0.592$ F = N.R. d.f. = 3,23

Therefore, price elasticity is estimated to be -0.44, which is within the range of the most frequently proposed elasticities.

Separate demand models for average municipal, maximum day municipal, peak hour municipal, and commercial/institutional are also presented. However, with each case the price variable was either not significant or not included in the model.

Data Base Information:

Study Area Data

Location and water users: 27 water utilities serving more than 10,000 people.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: mixed rates because of multi-site data.
User sector: all residential.
Area character: urban.

<u>Water Use Data</u>

Maximum number of cases: 27 observations.
Type of measurement: secondary data from the AWWA survey and mail questionnaires.
Measurement period: 1960.
Dependent variable: average annual residential use per connection (gpd).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: stepwise multiple regression.
Price variable specification: total residential marginal price ($/1,000 gallons).

Minimum, maximum, and mean variable values:

Q = 116-496; 245 gallons/day/connection (n = 38).
P_{ms} = 0-0.96; $0.42/1,000 gallons (n = 36).

Price elasticity: -0.44 (log with marginal price).

32 Hogarty, Thomas F., and Robert J. Mackay. 1975. The Impact of Large Temporary Rate Changes on Residential Water Use. Water Resources Research 11(6):791-94.

Abstract:

The purpose of this article is to present evidence that individual residents may decrease domestic water usage in the short run (three months) and the long run (one year) if the marginal rates are significantly increased. Furthermore, although the rate increases may be only temporary, the water usage may remain at decreased levels.

Hogarty and Mackay used monthly time-series data from 120 metered residential households from the suburban community of Oak Manor, Virginia. The time period utilized was from the fourth quarter of 1971 to the fourth quarter of 1973. During the first quarter of 1972, Oak Manor water service was transferred from the county to Blacksburg, Virginia. However, annexation of Oak Manor to Blacksburg did not occur until January 1973. Therefore, residents of Oak Manor paid higher external rates for 10 months during 1972. When Oak Manor was annexed, the water rates decreased to below the original county rates. The residents of Oak Manor had full information about rate increases (decreases) and water conservation tips due to community newsletters.

The authors calculated arc elasticities for each household after the marginal rate increase. The mean elasticity of the households during the short run (three months) was calculated to be -0.86, which is statistically significant at the 0.05 level for a one-tailed test. Furthermore, the mean elasticity of the households during the long run (one year) was calculated to be -0.56, which is statistically significant at the 0.01 level for a one-tailed test. The mean elasticities for the rate decreases were found to be either positive or statistically insignificant, or both.

Hogarty and Mackay concluded that after the rate increase, the residents reacted by substantially reducing their water usage and remaining at lower usage levels despite later rate reductions. The authors gave two possible reasons for the Oak Manor residents' actions. First, the residents may have reacted to expected decreases in their disposable income. Therefore, this income effect may have caused these consumers to take steps to decrease their usage. Secondly, a substitution effect may have occured even in the short run. In this aspect, consumers may have opted to increase other inputs into the household, such as increasing household labor. After the rate increase, the residents also may have repaired leaks and developed habits that utilized their water-using appliances more efficiently. Therefore, these effects may also have extended to the long run period and even after the marginal rate decreased.

Data Base Information:

Study Area Data

Location and water users: 120 individual households in Blacksburg, Virginia.
Mean summer temperature: 72 degrees F.
Mean summer precipitation: 15 inches.
Mean summer evapotranspiration: 17 inches.
Mean summer moisture deficit: 8 inches.
Water rates: decreasing block rate with incorporated service charge.
User sector: residential single-family.
Area character: suburban.

Water Use Data

Maximum number of cases: 1,080 observations.
Type of measurement: secondary data of individual users.
Measurement period: fourth quarter 1971 to fourth quarter 1973.
Dependent variable: price elasticity of household.
Summer season definition: not specified.
Winter season definition: not specified.
Price variable specification: marginal price for each user in sample.
Estimating technique: arc elasticity.
Special circumstances: significant rate change and then annexation to community; full information of conservation programs.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticity: -0.86 in the short run and -0.56 in the long run.

33

Howe, Charles W., and F. P. Linaweaver, Jr. 1967. The Impact of Price on Residential Water Demand and its Relation to System Design and Price Structure. Water Resources Research 3(1):12-32.

Abstract:

This article presents one of the most extensive and reliable estimates of residential water demand functions, using a data set collected by the Johns Hopkins University's Residential Water Use Research Project. The data set consisted of observations on average values for water use, economic and climatic characteristics for 39 master-metered residential areas served by 16 water utilities and ranging from 34 to 2,373 dewlling units. Recordings of water use in 15-minute intervals were taken for periods varying from two to three years during 1961-63 and were subsequently aggregated to hourly, daily, seasonal, and annual figures. In-house (domestic) and summer sprinkling (outdoor) uses were separated with the latter divided into eastern and western regions of the country.

The best fit function for domestic demand in 21 metered residential areas with public sewer was estimated as:

(1) $$Q = 206 + \underset{(5.93)}{3.47}\, Y - \underset{(3.83)}{1.30}\, P_{ms}$$

$$R^2 = 0.72 \quad F = 22.8 \quad d.f. = 2,18$$

Double-log equations were estimated for summer sprinkling demand in metered residential areas with public sewer for regions west and east of the 100th meridian.

(2) West

$$\log Q = 3.053 - \underset{(2.19)}{0.703} \log P_{ms} + \underset{(1.88)}{0.429} \log Y$$

$$R^2 = 0.67 \quad F = 7.21 \quad d.f. = 2,7$$

(3) East

$$\log Q = -0.784 - \underset{(3.65)}{0.793} \log L + \underset{(6.83)}{2.93} \log M - \underset{(8.26)}{1.57} \log P_{ms}$$

$$+ \underset{(4.74)}{1.45} \log Y$$

$$R^2 = 0.93 \quad F = 19.0 \quad d.f. = 2,8$$

The equation for the eastern region has the wrong sign in the coefficient of the irrigable area (L).

Maximum day residential sprinkling demand functions are:

(4) West

$$\log Q = 3.583 - \underset{(0.30)}{0.076} \log L + \underset{(1.29)}{1.32} \log X - \underset{(1.25)}{0.388} \log P_{ms} + \underset{(1.36)}{0.438} \log Y$$

$R^2 = 0.80$ $F = 5.16$ d.f. = 4,5

(5) East

$$\log Q = -1.974 + \underset{(0.384)}{0.118} \log L - \underset{(2.08)}{10.4} \log X - \underset{(3.69)}{1.25} \log P_{ms} + \underset{(2.10)}{0.931} \log Y$$

$R^2 = 0.75$ $F = 4.56$ d.f. = 4,6

Where: X = maximum day potential evapotranspiration, in inches.

In addition to its use of an unsually high quality data set, this study provides exhaustive discussion of the impacts of price on water use coupled with very good presentation of results. Additional analyses of the Johns Hopkins' data were published by Howe (1982).

Data Base Information:

Study Area Data

Location and water users:
(1) 10 metered areas with public sewer in Oakland, Los Angeles, and San Diego;
(2) 11 metered areas with public sewer in Des Moines, Fort Worth, Little Rock, Washington, D.C., Baltimore, and Philadelphia;
(3) 5 metered areas with septic tanks in Des Moines, Baltimore, and Phildelphia;
(4) 8 flat-rate (unmetered) areas with sewer in Sacremento, Great Falls, and Denver;
(5) 5 apartment areas without individual apartment meters in San Diego, Denver, and Washington, D.C.

Mean summer temperature: N.R.
Mean summer precipitation: 0.15-12.3 inches.
Mean summer evapotranspiration: 11.70-16.84 inches.
Mean summer moisture deficit: 9.4-11.6 inches.
Water rates: varied due to multi-site study area.
User sector: residential.
Area character: urban, suburban.

Water Use Data

Maximum number of cases: 21.
Type of measurement: primary, readings of master-meters.
Measurement period: 1960.
Dependent variable:
(1) average annual quantity demanded for domestic puposes in gallons per dwelling unit per day (gpd/du);
(2) average summer sprinkling demand in gpd/du;
(3) maximum daily sprinkling demand in gpd/du.
Summer season definition: June, July, August.
Estimating technique: ordinary least squares regression.
Price variable specification: marginal price adjusted by regional price index for average user in each master-metered area.

Minimum, maximum, and mean variable values and price elasticities:

Metered with public sewer (domestic):
Q = 150-344, 226 gallons/dwelling/day.
P_{ms} = 14.4-117.0, 40.1 cents
Elasticity = -0.231.

Metered with public sewer, West (sprinkling demand):
Q = 167-780, 387 gallons/dwelling/day.
P_{ms} = 24.0-61.3, 36.2 cents.
Elasticity = -0.73.

Metered with public sewer, East (sprinkling demand):
Q = 37-481, 185 gallons/dwelling/day.
P_{ms} = 17.4-102.0, 40.8 cents.
Elasticity = -1.57.

Metered with public sewer western areas (maximum day sprinkling demand):
Q = 323-1206, 707 gallons/dwelling/day.
P_{ms} = 24.0-61.3, 36.2 cents.
Elasticity = -0.388.

Metered with public sewer eastern areas (maximum day sprinkling demand):
Q = 160-983, 556 gallons/dwelling/day.
P_{ms} = 17.4-102.0, 40.8 cents.
Elasticity = -1.25.

Other Variables: market value of dwelling unit in $1000's, number of persons per dwelling unit, age of dwelling unit in years, average water pressure in psi, number of billing period per year, irrigable area per dwelling unit, summer potential evapotranspiration in inches, maximum day potential evapotranspiration in inches, summer precipitation in inches (min, max, and mean values for these variables are reported in the article with the breakdown by the type of areas).

34

Howe, W. Charles. 1982. The Impact of Price on Residential Water Demand: Some New Insights. Water Resources Research 18(4):713-16.

Abstract:
The objective of this article was to estimate water demand functions from the Johns Hopkins' data set (see Howe and Linaweaver 1967), using model specifications which included Nordin's bill difference variable. This variable represents the difference between the consumers' actual bill and what the cost of water would be if it were billed at the marginal price:

$$D = TR - Q \times P_m$$

This variable is designed to measure the effects of changes in inframarginal price changes on water use.

The newly specified function was estimated for domestic (in-house) residential water demand in 27 metered areas with public sewer to be:

$$(1)\ Q = \underset{(9.42)}{234} - \underset{(-1.65)}{7.20\ D} + \underset{(5.05)}{4.04\ Y} - \underset{(-2.78)}{127.90\ P_{ms}}$$

R^2 = N.R.   F = N.R.   d.f. = 3,17

All variables in this equation except D are significant at 0.05 level of probability. The reestimated functions for total summer household demand (domestic plus sprinkling) in 11 eastern areas is:

$$(2)\ Q = \underset{(4.13)}{385} - \underset{(-0.81)}{12.11\ D} + \underset{(1.52)}{8.01\ Y} - \underset{(-3.41)}{795.65\ P_{ms}} + \underset{(2.45)}{157.77\ M}$$

R^2 = N.R.   F = N.R.   d.f. = 4,6

The bill difference (D) and house value (Y) are not significant at 0.05 probability level.

The reestimated function for total summer demand in 10 master-metered residential areas with public sewer in the west is:

$$(3)\ Q = \underset{(1.68)}{430} + \underset{(1.65)}{57.77D} + \underset{(2.55)}{13.11\ Y} - \underset{(-0.73)}{342.63\ P_{ms}} - \underset{(-0.85)}{39.98\ M}$$

R_2 = 0.84   F = N.R.   d.f. = 4,5

In the above equation only the coefficient of Y is significant at 0.05 level.

The new elasticity estimate with respect to changes in the marginal price alone was calculated using the formula:

$$\text{elasticity } (\eta) = \left(\frac{dQ}{dP_m} + \frac{dQ}{dD} * \frac{dD}{dP_m}\right) \frac{P}{Q} \text{ means}$$

which accounts for the effect of changes in marginal price on the bill difference. The elasticties for the revised models were generally lower then those found in the 1967 study.

Data Base Information:

See Howe and Linaweaver (1967).

Mean variable values and price elasticities:

Domestic use in 27 metered areas with public sewer:
Q' = 12.75 units/billing period.
Q = 261 gallons/dwelling/day.
P = \$0.40.
η = -0.06.

Summer use in 11 eastern areas:
Q' = 18 units/billing period.
Q = 415 gallons/dwelling/day.
P = \$0.408.
η = -0.568.

Summer use in 10 western areas:
Q' = 7.5 units/billing period.
Q = 658 gallons/dwelling/day.
P = \$0.36.
η = -0.427.

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35 Jones, C. Vaughan, and John R. Morris. 1984. Instrumental Price Estimates and Residential Water Demand. Water Resources Research 20(2):197-202.

Abstract:

Based on a cross-sectional sample of 326 single-family households from metropolitan Denver, Colorado, estimates of "residential water demand are developed which incorporate instrumental price variables for the average price and the variables of the two-part price specification." Data for 1976 were collected from the 10 water utilities, county tax assessors, and mail questionnaires from the households (note data base in Morris and Jones 1980).

The authors state "the strategy of instrumental estimation is to identify a new variable or variables correlated but orthogonal to the disturbance term of the regression. These instrumental price estimates and other explanatory variables are regressed on household by household water use. Specifying suitable instruments for average price or the two-part price specification recovers the consistency property of OLS estimators." Therefore, "the observed average price is related to average price in consumer decisions and an error term. A summer or winter marginal price is associated with an estimate of typical water use in that season through the rate schedule relation. The instrumental estimate of the inframarginal rate variables is the sum of bills for these typical users in summer and winter net of the cost of purchasing this amount valued at the respective marginal prices, including revelant sewer charges."

The residential models use annual residential demand (1976) as the dependent variable; and *instrumental average price in dollars* (P_{ac}); instrumental summer marginal water price in dollars (P_{ms}); total dollar amount of instrumental estimates of the value of the summer and winter inframarginal rate variables (D_{as}); estimated 1976 family income in \$1,000 (I); and number of residents in the household (H). Because of missing observations in explanatory variables, the annual regressions are based on 326 households. Linear, multiplicative, and semilog functions are presented in the article; however, the logarithmic function provided better results. The results of the OLS regression in double-log forms are:

(1) Average price specification

$$\log Q = 3.46 - \underset{(3.05)}{0.34} \log P_{ac} + \underset{(2.02)}{0.46}\, I + \underset{(3.44)}{0.17} \log H$$

$R^2 = 0.23 \quad F = 32.09 \quad N = 326$

(2) Two-part price specification

$$\log Q = 4.42 - \underset{(2.04)}{0.21} \log P_{ms} - \underset{(2.75)}{0.23} \log D_{as} + \underset{(3.76)}{0.40} \log I + \underset{(1.94)}{0.14} \log H$$

$R^2 = 0.25 \quad F = 11.57 \quad N = 326$

The t-values are presented in parentheses. "The overall explanatory power (R^2) of the regressions is typical for OLS estimates on cross-sectional microdata. The F-statistic indicates that the variables of the average price specification are somewhat more strongly related to the dependent variable than those of the two-part price specification, although both are significant at a 1 percent level or higher." The price elasticity estimates in the double-log model are -0.34, -0.21, and -0.23 for average, marginal, and inframarginal prices respectively.

Data Base Information:

Study Area Data

Location and water users: sampled 326 household in the Denver, Colorado, area.
Mean summer temperature: 65-70 degrees F.
Mean summer precipitation: 6-8 inches.
Mean summer evapotranspiration: 14-15 inches.
Mean summer moisture deficit: 9-10 inches.
Water rates: mixed rates due to variation among water districts.
User sector: residential single-family.
Area character: urban, suburban.

Water Use Data

Maximum number of cases: 326 cases (after deletion of cases with missing observations).
Type of measurement: secondary data on consumption from tax assessor and mail questionnaire.
Measurement period: 1976.
Dependent variable: average annual household water consumption (1,000 gallons).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: (1) instrumental average price; (2) summer marginal water price; and (3) total dollar amount of instrumental estimates of the value of the summer and winter inframarginal rate variables.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: (1) average price = -0.18 (linear) to -0.34 (log); (2) marginal price = -0.07 (linear) to -0.21 (log) and (3) difference = -0.07 (linear) to -0.23 (log).

36

Lynne, Gary D., William G. Luppold, and Clyde Kiker. 1978. Water Price Responsibleness of Commercial Establishments. Water Resources Bulletin 14(3):719-29.

Abstract:

This article presents the results of a cross-section regression analysis of commercial establishments in the Miami (SMSA), Florida. A basic contention of this study is that "price is an important variable in determining the quantity of water purchased by a commercial firm. Questionnaires were used to collect information on store area, restaruant area, and other variables from the following types of establishments: department stores, grocery stores, supermarkets, motels and hotels, restaurants, drinking establishments, furniture stores, drug stores, hardware stores, and men's apparel stores." Of the approximate 900 questionnaires sent to various establishments, 257 were returned in usuable form. The resulting demand models are presented in partial log forms. The equations of best fit are:

(1) Department stores

$$\log Q = \underset{(1.37)^{**}}{1.3960} - \underset{(4.63)^{*}}{1.0704}\,P_{ms} + \underset{(4.11)^{*}}{0.6489}\,\text{Log } X_1 + \underset{(2.00)^{**}}{0.0004}\,X_2$$

$R^2 = 0.78$ $N = 20$ $F = \text{N.R.}$

(2) Groceries and supermarkets

$$\log Q = \underset{(12.29)^{*}}{2.8876} - \underset{(5.03)^{*}}{0.7191}\,P_{ms} + \underset{(3.6)^{*}}{0.0036}\,X_1 + \underset{(3.82)^{*}}{0.9827}\,D_1$$

$R^2 = 0.73$ $N = 19$ $F = \text{N.R.}$

(3) Motels and hotels

(a) utilized primary data from mail questionnaire.

$$\log Q = \underset{(3.24)^{*}}{1.5677} - \underset{(3.29)^{*}}{0.2404}\,P_{ms} + \underset{(4.57)^{*}}{0.0274}\,NR + \underset{(4.4)^{*}}{0.1012}\,P_2 + \underset{(1.1)}{0.0011}\,DB$$

$R^2 = 0.95$ $N = 40$ $F = \text{N.R.}$

(b) based on secondary data from a state regulatory agency.

$$\log Q = \underset{(11.52)^{*}}{3.2500} - \underset{(2.14)^{*}}{0.1114}\,P_{ms} + \underset{(48.4)^{*}}{0.242}\,NR + \underset{(1.63)^{**}}{0.0228}\,P_2$$

$R^2 = 0.94$ $N = 93$ $F = \text{N.R.}$

(4) Eating and drinking establishments

$$Q = \underset{(0.58)}{-15.2308} - \underset{(0.85)}{13.973}\, P_{ms} + \underset{(3.62)^*}{11.155} \log DH + \underset{(2.64)^*}{8.055} \log BH$$

$R^2 = 0.25$ N = 24 F = N.R.

(5) Other commercial businesses

$$Q = \underset{(0.90)}{-12.5863} - \underset{(1.43)^{**}}{10.2470} \operatorname{Log} P_{ms} - \underset{(1.07)^{**}}{0.1662}\, X_1 + \underset{(2.77)^*}{0.510}\, X_3$$

$$+ \underset{(2.11)^*}{17.4382}\, D_2$$

$R^2 = 0.35$ N = 34 F = N.R.

Where: Q = average monthly water purchase in thousands of gallons; P_{ms} = water price per thousand gallons; X_1 = area of store in hundreds of square feet; X_2 = area of restaurant in square feet; D_1 is a dummy variable, 1 if kitchen present, 0 otherwise; NR = number of rooms for rent; P_2 = weighted average of the maximum prices for all rooms in the motel or hotel; DB = dining room plus bar room area (tens of square feet); DH = dining room area (hundreds of square feet) times hours open per week (X_3); BH = bar room area (hundreds of square feet) times hours open per week; and D_2 is a dummy variable, 1 if store had water-cooled air conditioning, 0 otherwise. The R^2 value is adjusted for degrees of freedom. The * indicates that the coefficient is significant at least at the 0.05 probability level while ** indicates significance at least at the 0.20 level. The price elasticities were calculated at the mean marginal price of each sample and are presented in the data base information below.

For department stores, the price elasticity varies and becomes greater than one at a price of $0.93 per thousand gallons of water consumed. The hypothesis that demand is inelastic was rejected. All the other categories indicated that demand is inelastic, yet price sensitive. A discussion of the statistical results for each is presented seperately. No F ratio for the significance of the regression equations is presented.

Data Base Information:

Study Area Data

Location and water users: commercial establishments in the Miami Standard Metropolitan Statistical Area (SMSA), Florida.
Mean summer temperature: 82 degrees F.
Mean summer precipitation: 28 inches.
Mean summer evapotranspiration: 19 inches.
Mean summer moisture deficit: 2.2 inches.
Water rates: mixed rates due to sample of 18 water companies.
User sector: commercial.
Area character: metropolitan.

Water Use Data

Maximum number of cases: varies by model (230 in total).
Type of measurement: actual water consumption and price data collected from 18 water companies; supplementary data was supplied by questionnaires from the businesses.
Measurement period: not specified.
Dependent variable: average monthly water use in thousands of gallons per month.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: multiple regression.
Price variable specification: marginal price for average user in each sample.

Minimum, maximum, and mean variable values and price elasticities:

Department stores: mean Q = 179,000 gallons; mean P = $1.24; elasticity = -1.33.
Grocery stores: mean Q = 42,000 gallons; mean P = $1.06 elasticity = -0.76.
Motels and hotels:
Eq. (a): mean Q = 248,000 gallons; mean P = $1.00; elasticity = -0.24.
Eq. (b): mean Q = 287,000 gallons; mean P = $1.02; elastitity = -0.12.
Eating and drinking establishments: mean Q = 53,000 gallons; mean P = $0.66 per 1000 gallons; elasticity = -0.174 (with a large standard error).
Other commercial businesses: mean Q = 21,5000 gallons; mean P = $0.88 per 1,000 gallons; elasticity = -0.48 (with a large standard error).

37

Male, James W., Cleve E. Willis, Frederick J. Babin, and Charles J. Shillito. 1979. Analysis of the Water Rate Structure as a Management Option for Water Conservation. Water Resources Research Center publication no. 112. University of Massachusetts. Amherst.

Abstract:

The purpose of this study was to assess the potential for residential water conservation by altering the price structure. Two specific objectives of this report were (1) to develop a water demand model, and (2) to investigate the effects of alternative pricing structures on both the quantity of water demanded and the revenues received by the water utility. Data for quantity, price, and persons per meter were obtained from the American Water Works Association's "Survey of Operating Data for Water Utilities," 1965 and 1970. Income and population data were supplied by the 1970 census. This study utilized 56 observations of water utilities from six northeastern states (Massachusetts, Maine, Conneticut, New York, New Jersey, and Pennsylvania). It is not stated whether any of the monetary figures were adjusted to real prices.

Using ordinary least square regression, three functional models were estimated: linear, power, and exponential. On theoretical grounds, the linear and exponential models were considered more appropriate. The exponential model is essentially the same as the power form, however price is treated as an exponent and allows elasticity to vary with price level. The three water demand models are presented with their t-statistics in parenthesis.

(1) Linear

$$Q = \underset{(-0.516)}{-0.194} - \underset{(-2.982)}{0.273}\,P_{au} + \underset{(1.007)}{0.027}\,I + \underset{(4.599)}{0.188}\,H + \underset{(2.521)}{0.043}\,S$$

$R^2 = 0.50$ F = N.R.   d.f. = 51

(2) Power (log transformation)

$$\log Q = \log \underset{(-4.99)}{0.066} - \underset{(-8.54)}{0.680}\,\log P_{au} + \underset{(2.26)}{0.459}\,\log I + \underset{(4.36)}{0.724}\,\log H + \underset{(1.59)}{0.065}\,\log S$$

$R^2 = 0.73$ F = N.R.   d.f. = 51

(3) Exponential (log transformation)

$$\log Q = \log \underset{(-4.29)}{0.082} - \underset{(7.70)}{0.505}P_{au} + \underset{(2.53)}{0.545}\,\log I + \underset{(5.14)}{0.895}\,\log H + \underset{(1.57)}{0.069}\,\log S$$

$R^2 = 0.69$ F = N.R.   d.f. = 51

Where: Q = average annual demand/household (100,000 gallons); P = average price ($/1,000 gallons); I = median family income ($/1,000/year); H = average number of persons per meter; and S = population density (1,000/square mile). Average price and household size were significant at the 0.01 probability level in all models; income was significant at the 0.05 level in models (2) and (3); and density was significant at the 0.05 level only in the linear model. The authors state that "the hypothesis of no autocorrelation could not be rejected in any of the three cases," however there was no elaboration on this point. The models yielded a range of price elasticities from -0.20 to -0.37, all calculated at mean values.

The exponential model, which explained 69 percent of the variance, was accepted for application to a case study to estimate the degree of consumer responsiveness to three different rate structures. Results showed an estimated reduction of residential demand in Amherst, Massachusetts of approximately 15 percent for a three-month water short period.

Data Base Information:

Study Area Data

Location and water users: 56 observations of water utilities in 6 northeastern states.
Mean summer temperature: 62-70 degrees F.
Mean summer precipitation: 4-9 inches.
Mean summer evapotranspiration: 10-16 inches.
Mean summer moisture deficit: 4.6-9.3 inches.
Water Rates: mixed rates due to multi-site data.
User sector: metered residential.
Area character: it was not specified as to whether the 56 observations were similiar in area character.

Water Use Data

Maximum number of cases: 56 cases.
Type of measurement: water sales to metered residential customers.
Measurement period: 1965 and 1970.
Dependent variable: quantity of water demanded per household (per meter) in 100,000 gallons per year.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: average water price for all customers of a utility ($/1,000 gallons).

Minimum, maximum, and mean variable values:

Q = 0.13-3.06; 0.99 in 100,000 gallons/meter/year.
P_{au} = 0.22-4.86; $0.73 /1,000 gallons.
I = 7.3-17.8; 10.57 in $1,000/year.
H = 2.98-10.83; 4.74 persons/meter.
S = 0.40-13.94; 4.77 in 1,000 persons/square mile.

Price elasticities: (1) linear model = -0.20 at the mean; (2) power model = -0.68 (mean); and (3) exponential model = -0.37 (mean).

38

Metcalf, Leonard. 1926. Effect of Water Rates and Growth in Population upon per Capita Consumption. Journal of the American Water Works Association 15(1):1-20.

Abstract:

This article is one of the earliest studies of municipal water demand. Although no models were developed and no elasticities calculated, this study remains at the forefront of the field of water demand.

Metcalf realized and stressed the need for annual or periodical, disaggregated water consumption data. In his study, Metcalf collected data for 30 cities in the United States. These records were obtained from correspondence with the superintendents of the various water supply utilites. Using average daily consumption (1920-24) and 1920 census data, Metcalf calculated daily per capita water consumption (gallons/capita/day) for the 30 U.S. cities. He then plotted three trend lines representing the rates of per capita consumption for the 30 cities, plotted in each case for the domestic, intermediate, and manufacturing rates of the city. The domestic, intermediate, and manufacturing rates are the average rates for assumed quantities of 25,000 gallons, 250,000 gallons and 2,500,000 gallons per month, respectively. Since each of the three trend lines used the per capita figures, they displayed the same slope. Furthermore, since the data could not be disaggregated into the three components , no demand curves could be presented. In the article, Metcalf presents a table that indicates the average decrease in per capita consumption with an increase in rates. This table is presented as:

Variations in per capita consumption corresponding to given variation in water rates, from data from 30 representative cities, 1920-24.

Increase in rates	Decrease in rates
percent	percent
20	13
40	22
60	29
80	35
100	40

Source: Metcalf 1926.

By dividing column two by column one, elasticities can be estimated. For example, a 20 percent increase in water rates would indicate an elasticity of -0.65 and a 100 percent rate in would indicate an elasticity of -0.40.

Data Base Information:

Study Area Data

Location and water users: 30 water supply systems in the U.S.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: mixed rates due to multi-site data.
User sector: aggregate municipal.
Area character: urban.

Water Use Data

Maximum number of cases: 30 cases.
Type of measurement: secondary, aggregate water consumption.
Measurement period: 1920-24 consumption data; and 1920 census data.
Dependent variable: N.A.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: scatterplot and fitted trend lines.
Price variable specification: average price for all customers of a utility.

Minimum, maximum, and mean variable values: no values reported.

Price elasticities: -0.65 for a 20 percent rate increase to -0.40 for a 100 percent rate increase.

39 Morgan, W. Douglas. 1974. A Time Series Demand for Water Variables. Water Resources Bulletin 10(4):697-702.

Abstract:

This study presents the results of an examination of the effects of the imposition of a $3.00 lump sum payment each bimonthly billing period plus an increase of $0.04 per 100 cubic feet of water consumed on 34 single-family residences in Santa Barbara, California. The water district supplied water consumption data for the before surcharge period (1967-70) and then with the surcharge (1971-72). Ordinary least squares multiple regression analysis was performed using binary independent variables. Two water consumption models were estimated: one to test the effects of the surcharge on induvidual accounts and the other to evaluate the sum of all accounts over the billing periods. The two equations are presented as:

$$(1)\quad Q_1 = \underset{}{24.82} - \underset{(-5.16)}{41.71A_2} + \underset{(2.21)}{17.88A_3} - \underset{(-3.93)}{31.75A_3}\ldots\ldots \underset{(-2.16)}{-17.43A_{34}}$$

$$- \underset{(3.32)}{11.42S_2} + \underset{(4.53)}{18.66S_3} + \underset{(11.92)}{52.33S_4} + \underset{(17.60)}{78.28S_5} + \underset{(9.61)}{39.24S_6}$$

$$+ \underset{(5.35)}{1.24D} - \underset{(2.07)}{0.0076F} - \underset{(-4.38)}{15.97P}$$

$R^2 = 0.70$ Se = 27.9 Df = 774 N = 816 F = N.R.

$$(2)\quad Q_2 = \underset{(4.72)}{1212.91} - \underset{(-1.47)}{307.07S_2} + \underset{(1.28)}{310.16S_3} + \underset{(5.52)}{1499.91S_4}$$

$$+ \underset{(8.18)}{2226.26S_5} + \underset{(4.79)}{1143.26S_6} + \underset{(3.28)}{32.786D}$$

$$- \underset{(1.65)}{39.42F} - \underset{(2.29)}{496.09P}$$

$R^2 = 0.93$ Se = 332.6 N = 31

Where: Q_1 = water consumption per billing period per account (100 cubic feet); Q_2 = sum of water consumed in all accounts per billing period; A_2 through A_{34} are binary variables representing each account in sample (omitted in equation (2) due to summation of accounts); S_1 through S_6 are seasonal dummies that also represent billing periods within a year; D = trend variable than linearly increases by one unit each billing period; F = precipitation during billing period (hundredths of inches); P = binary price variable such that P = 1 during the surcharge period and 0 otherwise. T-values are in parentheses, Se is the standard error of estimate, and N equals the sample size.

The significant price coefficient of equation one represents "a 15.97 hundred cubic feet reduction in water consumed per account per billing period because of the imposition of the surcharge the last year of the sample." From equation (2), "the average quantity of water consumed was reduced by 15.4 percent yielding an average price elasticity of demand of -0.49."

Data Base Information:

Study Area Data

Location and water users: 34 households in Santa Barbara, California.
Mean summer temperature: 68 degrees F.
Mean summer precipitation: 0 inches.
Mean summer evapotranspiration: 11 inches.
Mean summer moisture deficit: 11 inches.
Water rates: not specified.
User sector: residential single-family.
Area character: suburban.

Water Use Data

Maximum number of cases: 816 observations.
Type of measurement: secondary for individual users.
Measurement period: January 1967-February 1972 (31 billing periods).
Dependent variable: water consumption during billing period by each account (100 cubic feet); quantity of water consumed (in all accounts) during each billing period.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: binary price variable which is equal to one when surcharge was imposed and zero otherwise.

Minimum, maximum, and mean variable values: No variable values reported.

Price elasticity: -0.49 was calculated for all accounts.

40

Morgan, W. Douglas, and Jonathan C. Smolen. 1976. Climatic Indicators in the Estimation of Municipal Water Demand. Water Resources Bulletin 12(3):511-18.

Abstract:

The purpose of this paper was to develop a regression equation for water demand that accounts for climatic variation within a data set. Monthly municipal water delivery data were collected for 33 cities in Southern California in 1970, giving a total of 396 observations. Three alternative climatic indicators were tested: (1) temperature and precipitation, (2) potential evapotranspiration minus precipitation (PE - F), and (3) monthly binary seasonal variables. The model utilizing temperature and precipitation performed much better in explaining variance in water deliveries. The equations in this model have lower standard errors (Se) and higher F-statisics than the models using PE-F or binary variables.

Using this model, four major equations are presented: (1) the total twelve-month period, (2) a five-month wet season (November-March) to approximate domestic use, (3) a seven-month dry season (April-October) including both domestic and sprinkling use and (4) sprinkling demand calculated by subtracting minimum wet period monthly use for each area (domestic) from the dry period usage (domestic and sprinkling). The four regression estimates are:

(1) Total

$$Q = \underset{(-7.29)}{-253.73} - \underset{(-10.29)}{1.041P_{au}} + \underset{(4.53)}{0.0067I} + \underset{(19.50)}{8.409T} - \underset{(-2.71)}{5.411F}$$

$R^2 = 0.68$ Se = 64.31 F = 212.50 N = 396
Price elasticity = -0.44

(2) Wet season (domestic)

$$Q = \underset{(-0.78)}{-33.778} - \underset{(-8.00)}{0.7273P_{au}} + \underset{(6.35)}{0.0089I} + \underset{(4.06)}{3.169T} \underset{(-1.00)}{-1.648F}$$

$R^2 = 0.45$ Se = 37.80 F = 33.17 N = 165
Price elasticity = -0.45

(3) Dry season

$$Q = \underset{(-3.26)}{-179.63} - \underset{(-8.11)}{1.259\ P_{au}} + \underset{(3.50)}{0.0076I} + \underset{(12.05)}{7.494T} + \underset{(4.59)}{149.689F}$$

$R^2 = 0.63$ Se = 71.38 F = 97.18 N = 231
Price elasticity = -0.43

(4) Sprinkling

$$Q = -176.603 - 0.860P_{au} - 0.0014I + 6.28T + 139.20F$$
$$\quad (-3.33) \qquad (-5.74) \qquad (0.67) \qquad (10.47) \quad (4.42)$$

$R^2 = 0.54$ Se = 68.85 F = 66.578 N = 165
Price elasticity = -0.55

Where: Q = monthly municipal water use (gallons per capita per day); P_{au} = average price of municipal water delivered in dollars per acre foot; I = median family income ($1,000); T = mean monthly temperature (F); F = precipitation (hundreths of an inch); R^2 = coefficient of multiple determination not adjusted for degrees of freedom, and Se = standard error of regression corrected for degrees of freedom. Values in parentheses are t-statistics. Price elasticities are evaluated at the mean. As expected, the higher price elasticity occurs during sprinkling usage. A model utilizing potential evapotranspiration minus precipitation (rather than precipitation and temperature) was also found to be significant, and gave similar results.

Data Base Information:

Study Area Data

Location and water users: 33 cities in Southern California.
Mean summer temperature: 60-70 degrees F.
Mean summer precipitation: 0-1 inch.
Mean summer evapotranspiration: 10-18 inches.
Mean summer moisture deficit: 10-17.4 inches.
Water rates: mixed rates in multi-site data.
User sector: aggregate municipal.
Area character: urban.

Water Use Data

Maximum number of cases: 396 observations.
Type of measurement: aggregate water sales.
Measurement period: 1970.
Dependent variable: monthly municipal water use (gallons/capita/day).
Summer season definition: November-March.
Winter season definition: April-October.
Estimating technique: multiple regression.
Price variable specification: average price for all customers of utility.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: model using precipitation and temperature had a range from -0.43 to -0.58; model using PE - F had a range from -0.44 to -0.58.

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Morris, John R., and Clive V. Jones. 1980.
Water For Denver: An Analysis of the Alternatives.
Environmental Defense Fund, Inc. Denver, Colorado.

Abstract:

This report contains the results of the Denver Water Conservation Study performed by the University of Colorado, Denver. The study is based on utility bill, tax assessment, and questionnaire data of 384 single-family residential customers served by 21 water districts in the Denver metropolitan area. Information was collected on over 100 variables for the base year 1976.

Four linear economic demand models were developed using ordinary least squares regression analysis. The first model, developed for 384, aggregated data into the 21 districts. The linear model is estimated as:

$$(1)\quad \underset{}{Q_1} = \underset{(2.1)}{68.7} - \underset{(-2.3)}{0.96\,P_{ms}} + \underset{(3.7)}{0.43\,I} + \underset{(2.8)}{0.59\,L}$$

$$R^2 = 0.65 \quad F = 10.55 \quad DF = 3,17$$

Where: Q_1 = district-wide average annual household water use (1,000 gallons); P_{ms} = marginal price in each district for the final 1,000 gallons consumed each billing period during the irrigation season (cents/1,000 gallons); I = average family income ($100); and L = average residential lot size (100 square feet). The t-values in parantheses indicate that the three variables are significant at the 0.05 level. The F-statistic indicates that the equation is significant at the 0.01 level. Evaluated at the means , the price elasticity is estimated as -0.39.

The second model used additional data for each of the same 384 individual, metered households. The model using the individual household data is:

$$(2)\quad Q_2 = \underset{(4.68)^*}{90.07} - \underset{(-2.61)^*}{0.42\,P_{mc}} + \underset{(3.36)^*}{0.17\,I} + \underset{(8.15)^*}{0.63\,L} + \underset{(2.68)^*}{0.45\,HS}$$

$$\underset{(-1.37)}{-3.57\,HA} - \underset{(-3.76)^*}{50.23\,W} \underset{(-2.72)^*}{-7.61\,OP} - \underset{(-2.08)^*}{11.20\,TB}$$

$$\underset{(-0.93)}{-5.31\,SH} + \underset{(3.30)^*}{9.29\,SB} + \underset{(0.67)}{4.04\,RA}$$

$$R^2 = 0.37 \quad F = 20.2 \quad DF = 11 \text{ and } 372$$

Where: Q_2 = annual household water use (1,000 gallons); P_{mc} = marginal price of each user; HS = house floor space (100 square feet); HA = coded age of house; W = presence of a well on the property; OP = coded opinions on the price of water, TB = brick in the toilet; SH = low flow shower head; SB = number of baths and showers taken in a day; RA = the presence of rationing in 1977. The asterisk indicates significance at the 0.05 level. HA is significant at the 0.10 level while SH and RA do not have significant t-values. The F-value indicates that the equation as a whole is significant at the 0.01 level. When evaluated at the means, the price elasticity is -0.16.

Further information on the structure of demand is provided by two additional regressions, for indoor and outdoor uses specified on a sample of district wide averages. The results of the indoor regression are shown in equation (3).

$$(3)\quad \underset{}{Q_W} = \underset{(6.06)}{61.7} - \underset{(1.16)}{0.12\,P_W} + \underset{(5.66)}{0.20\,I} - \underset{(2.88)}{0.16\,L}$$

$R^2 = 0.66$ $F = 11.21$ $Df = 17$

Where: Q_W = average annual indoor use (12 times the monthly average in January, February, November and December) per household by district; and P_W = winter marginal price. The F-value indicates that the equation is highly significant, and price is the only nonsignificant variable with an elasticity equal to -0.09.

The results of the outdoor regression are shown in equation (4).

$$(4)\quad Q_S = \underset{(0.44)}{13.04} - \underset{(2.49)}{0.94\,P_S} + \underset{(2.25)}{0.23\,I} + \underset{(3.98)}{0.75\,L}$$

$R^2 = 0.64$ $F = 9.96$ $Df = 17$

Where: Q_S = average annual use per household during March through October less indoor use; and P_S = summer marginal price all the independent variables are significant at the 0.05 level, and the F-value indicates the equation is significant at the 0.01 level. Evaluated at the means, the price elasticity for outdoor consumption is -0.73.

Data Base Information:

Study Area Data

Location and water users: 384 customers in 21 Denver metropolitan area water districts.
Mean summer temperature: 65-70 degrees F.
Mean summer precipitation: 6-8 inches.
Mean summer evapotranspiration: 14-15 inches.
Mean summer moisture deficit: 9-10 inches.
Water rates: mixed rates due to variation in the 21 districts: 11 districts used uniform rates; 5 used declining block rates; and 5 used increasing block rates.
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: 21 in model (1); 384 in model (2).
Type of measurement: Secondary data on consumption from water utility; supplementary data from tax assessor and mail questionnaire.
Measurement period: 1976.
Dependent variable: average annual household water consumption (1,000 gallons).

Summer season definition: March-October.
Winter season definition: November-February.
Estimating technique: ordinary least squares regression.
Price variable specification: (1) marginal price for average user in each district; calculated in each district as the cost charged for the final 1,000 gallons consumed in each billing period during the irrigation season. (2) marginal price for each user in the sample.

Minimum, maximum, and mean variable values:

Q_1 = mean: 170,100 gallons/household/year.
Q_2 = mean: 165,100 (same units).
Q_w = mean: 82,600 (same units).
Q_s = mean: 87,500 (same units).

Price elasticity = -0.16 to -0.39; indoor = -0.09; outdoor = -0.73.

42

Pope, R. M., Jr., M. M. Steppl, and J. S. Lytle. 1975. Effects of Price Change upon the Domestic Use of Water over Time. Water Resources Research Institute. Clemson University. North Carolina.

Abstract:
The primary objective of this study was to develop residential water demand functions and to determine the price elasticity. Time-series data for periods before and after the price changes in selected South Carolina communities were utilized for 36 months from 1965 to 1971.

The communities to be included in the study were selected on the basis on these criteria: a rate increase in recent years, use of monthly billings, and the maintainence and accessibility of individual consumer records. The four cities in this study, Greenwood, Marion, Rockhill, and Darlington, were also chosen on the basis of geographic dispersion, city size, economic base, and climatic differences. The response from a mail questionnaire and their corresponding monthly usage from the utilities yielded 1,464 observations for all communities. Consumption for each household was recorded for 12 months prior to the rate change and 24 months after, however the 36-month time periods were not the same for all communities.

A preliminary regression analysis to determine which variables were significant explanatory factors indicated that family size, city, number of bathrooms, lawn irrigation, clothes washer, dishwasher, and income were significant at the 0.01 level. Price was not included in the preliminary analysis. Price elasticities were computed by income class and by family size for each community for each of the 24 months following the price increase, using seasonally adjusted consumption data. The results for income indicated that there was no clear "turning point" in the 24-month period in which price elasticities begin to diminish. No statistical analysis was presented on the differences among income levels. The size of family also showed no distinct effect on the demand elasticity for water over time.

The aggregation of data to reflect annual consumption eliminated much variation and yielded better results. The price elasticity for domestic water yield a range from -0.182 to -0.512 (mean = -0.331) for the first year following the price change and a range of 0.094 to -0.318 (mean = -0.139) for the second year. The results indicated that the short-run elasticity is greater than in the long run. The decrease in elasticity from the first year to the second year is also shown for residential irrigators and nonirrigators. For the irrigators the mean elasticity dropped from -0.438 to -0.210. For the residential users who did not irrigate, the mean decreased from -0.258 to -0.109. Although no statistical evidence was provided, it was concluded that the general tendency was that the communities with greater price increases reflected higher elasticities.

Data Base Information:

Study Area Data

Location and water users: 1,464 households in four South Carolina communities.
Mean summer temperature: 75-80 degrees F.
Mean summer precipitation: 14-18 inches.
Mean summer evapotranspiration: 17-19 inches.
Mean summer moisture deficit: 6.2-10.6 inches.
Water rates: decreasing block.
User sector: residential single-family.
Area character: urban.

Water Use Data

Maximum number of cases: 1,464 observations.
Type of measurement: secondary data on consumption and price from utility; personal and financial household information obtained from a mail questionnaire of respondents.
Measurement period: 1965-71.
Dependent variable: annual water consumption, monthly water consumption.
Summer season definition: May-September.
Winter season definition: not specified.
Estimating technique: multiple regression and arc elasticity.
Price variable specification: average price for each user in sample.

Minimum, maximum, and mean variable values: no variable values reported.

Annual Price Elasticities of Water Demand, 1965-1971

Classification	Price Elasticity year 2[a]	Price Elasticity year 3[b]
Greenwood		
aggregate	-0.216	0.094
irrigators	-0.307	0.317
nonirrigators	-0.124	-0.147
Rock Hill		
aggregate	-0.512	-0.318
irrigators	-0.674	-0.429
nonirrigators	-0.357	-0.211
Marion		
aggregate	-0.415	-0.172
irrigators	-0.615	-0.452
nonirrigators	-0.342	-0.060
Darlington		
aggregate	-0.182	-0.158
irrigators	-0.156	-0.277
nonirrigators	-0.208	-0.017

[a] = the first 12-month period following the price increse; [b] = the second 12-month period following the price increase.
Source: Table 27 from the report.

43 Primeaux, Walter J., and Kennth W. Hollman. 1973. Price and Other Selected Economic and Socio-Economic Factors as Determinants of Household Water Consumption. In Water for the Human Environment Proceedings of tne First World Congress on Water Resources. Vol. 3. International Water Resources Association. Champaign, Illinois.

Abstract:

The purpose of this study was to determine the effect that price and other economic, socioeconomic, and climatic variables have on the quantity of water demanded in 402 single family households in northern Mississippi during 1971. The 14 Mississippi cities ranged in population size from about 5,500 to over 21,000 and were located in largely rural counties. The 14 communities were chosed because of the similiarity of socioeconomic and demographic characteristics of their populations.

It was hypothesized that residential water consumption was influenced by thirteen variables. The independent variables are: number of persons per residence (H); number of bathrooms per residence (X_1); number of dishwashers (X_2); number of clotheswashers (X_3); existence of a swimming pool (X_4); irrigable area in hundreds of square feet (L); house market vale in \$100 (Y); average maximum temperature in degrees F. (T); annual precipitation in inches (F); education level (X_5); age of head of houshold; race; and average price of water per 1,000 gallons at mean level of consumption in each municipality (P_{au}). In a preliminary ordinary least squares regression analysis age and race were found to be insignificant. An estimated equation using the remaining variables is:

$$(1)\quad Q = \underset{}{-92.270} + \underset{(10.80)^*}{9.12\,H} + \underset{(1.93)^{**}}{8.29\,X_1} + \underset{(2.35)^*}{11.13\,X_2} + \underset{(2.92)^*}{12.43\,X_3}$$

$$+ \underset{(4.98)^*}{123.78\,X_4} + \underset{(3.11)^*}{0.14\,L} + \underset{(1.56)^{***}}{0.04\,Y} + \underset{(1.78)^*}{2.39\,T} - \underset{(-2.47)^*}{0.61\,F}$$

$$+ \underset{(3.27)^*}{5.188\,X_5} - \underset{(-3.95)^*}{22.74\,P_{au}}$$

R^2adj. = 0.56   F = N.R.   d.f. = N.R.
Price elasticity = -0.26 (mean)

The t-values are in parentheses; one asterisk indicates significance at the 0.01 level, two at the 0.05 level, and three at the 0.10 level. After eliminating several variables, the linear equation is estimated as:

$$(2)\quad Q = 47.96 + \underset{(11.76)^*}{10.51\,H} + \underset{(12.36)^*}{0.18\,Y} - \underset{(-6.33)^*}{32.50\,P_{au}}$$

R^2adj. = 0.47   F = N.R. d.f. = N.R.
Price elasticity = -0.37 (mean)

To account for nonlinearity, a logarithmic transformation was used:

$$(3)\ \text{Log } Q = 1.00 + \underset{(15.52)^*}{0.64 \log H} + \underset{(11.05)^*}{0.024 \text{ Log } Y} - \underset{(-7.68)^*}{0.45 \log P_{au}}$$

R^2adj. = 0.52   F = N.R.   d.f. N.R.
Price elasticity = -0.45 (constant)

In all cases, demand was found to be fairly inelastic given the current range of prices. The authors conclude that if water rationing is necessary, price would be an ineffective tool. However, this type of model could be used to estimate future demands on water systems.

Data Base Information:

Study Area Data

Location and water users: households in 14 Northern Mississippi cities.
Mean summer temperature: 78 degrees F.
Mean summer precipitation: 10-12 inches.
Mean summer evapotranspiration: 18-20 inches.
Mean summer moisture deficit: 10.8-14.0 inches.
Water rates: declining block with minimum charge.
User sector: metered residential single-family.
Area character: rural towns, small cities.

Water Use Data

Maximum number of cases: 402 households.
Type of measurement: secondary usage data from water utility meter records and mail questionnaire; household characteristics were collected by personal interviews.
Measurement period: 1971.
Dependent variable: monthly quantity of water demanded by residences (gallons).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: average price per 1,000 gallons at mean level of consumption in each municipality.

Minimum, maximum, and mean variable values: minimum and maximum values are not reported; mean values are:

$H = 3.26$, $X_1 = 1.39$, $X_2 = 0.24$, $X_3 = 0.76$, $X_4 = 0.004$, $L = 20.19$, $Y = 110.31$, $T = 62.90$, $F = 56.96$, $X_5 = 1.97$ (high school education), $P_{au} = 0.86$.

Price elasticities: -0.26 to -0.37 (linear with average price); -0.45 (log with average price).

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Rees, Judith A. 1969. Industrial Demand for Water: A Study of South East England. Weidenfeld and Nicolson, London School of Economics and Political Science.

Abstract:

This book presents an inquiry into industrial water use in southeast England. This study is based on a questionnarire survey of a random sample of 253 manufacturers located in the area. The survey was administered during the spring and summer of 1966.

The author reports the following multiple regression equations which used price as a determinant of water purchased by firms in various industry groups:

(1) Chemical firms

$$\log Q = a - 2.05798 \log P_m + 0.10626 \log Q_a$$

$R_2 = 0.37$ $F = 21.99$ for P_m and 2.31 for Q_a d.f. = 47

(2) Food firms

$$\log Q = a - 0.1312 P_m$$

$R_2 = 0.60$ $F = 19.33$ d.f. = 13

(3) Drink firms

$$Q = a - 427400.0 \log P_m$$

$R^2 = 0.36$ $F = 3.43$ d.f. = 6

(4) Non-metallic mineral firms

$$Q = a - 62{,}176.719 \log P_m$$

$R^2 = 0.31$ $F = 5.01$ d.f. = 11

Where: Q = quantity of purchased water in million gallons per year; P_m = price paid for metered supplies, pence/1,000 gallons; and Q_a = quantity of self-supplied water in mg per year.

The above industrial categories do not precisely coincide with the U.S. Standard Industrial Classification (SIC) categories. An aggregate ewuation with price variable for 162 firms was estimated to be:

(5) $\log Q = a + 1.089 \log E + 0.268 \log T + 0.814 \log P$

$R^2 = 0.35$ $F = 46.95$ for E; 6.51 for T; and 13.80 for P d.f. = 162

Where: T = tonnage of raw materials used by a firm, P = price paid for all purchased supplies, E = employment. In best-fit equations, the tonnage of raw material inputs and the number of persons employed were the best explanatory variables.

Overall, this book is a valuable reference for researchers of industrial water demand. The author gives an exhaustive analysis of the water use purposes, the sources from which the demand for water is satisfied, and also the effects of water availability on industrial location.

Data Base Information:

Study Area Data

Location and water users: Southeast England, 253 industrial firms.
Mean summer temperature: not specified.
Mean summer precipitation: not specified.
Mean summer evapotranspiration: not specified.
Mean summer moisture deficit: not specified.
Water rates: not specified, multi-site study area.
User sector: industrial.
Area character: varied, the firms located in 9 counties.

Water Use Data

Maximum number of cases: 253.
Type of measurement: secondary, annual water use reported by the firms.
Measurement period: 1965.
Dependent variable: annual quantity in gallons per year.
Estimating technique: OLS regression.
Price variable specification: unit price (probably average price) paid for metered purchased water.

Reported mean variable values and elasticities:

Chemical firms:
Q_a = 200.7 mg/year.
P_m = 31.75 pence/1,000 gallons.
Elasticity = -0.958 (estimated from the equation, log Q = $0.0302P_m$).

Food firms:
P_m = maximum 49 pence/1000 gallons.
Elasticity range: -3.288 to -6.713.

Drink firms:
Elasticity range: -1.3 to -4.1.

Non-metallic mineral firms:
Elasticity = -2.5 at the lowest observed price level.

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Ridge, R. 1972. The Impact of Public Water Utility Pricing Policy on Industrial Demand and Reuse. General Electric Technical Information Series. Prepared for the Office of Water Resources Research, Department of the Interior. Philadelphia, Pennsylvania.

Abstract:
The purpose of this study was to help expand the knowledge about the industrial demand for public water and its elasticity. The application of such knowledge can be used in three ways: (1) to project the effects of changes in price on industrial water demand, (2) to allow more accurate long range water demand forecasts, and (3) to provide industrial demand data that can contribute to the accuracy of other studies.

This study uses a cross-section of 90 plants in five four-digit SIC code industries; they are paper mills, paper-board mills, poultry dressing, malt brewing, and fluid milk processing. A mail survey of the plants supplied data about production levels, public water intakes, utility suppliers, size and age of plant, and employment. The marginal price of water was calculated from the water rate schedule of each respective plant.

Using a linear multiple regression analysis, statistically significant relationships are found in brewing and fluid milk plants and a possible relationship is found for poultry plants. However, no meaningful relationship is found in either the paper or paper-board industries. The results of the successful regression analyses are presented as:

(1) Brewery--SIC 2082

$$Q_1 = 370 - 208\ P_{mc} - 0.0157\ X_1$$

$R^2 = 0.64$ $F = 7.42$ d.f. = 9

Where: Q_1 = public water intake (gallons) divided by barrels output; P_{mc} = marginal water price ($/KG); X_1 = plant size (barrels/day).

(2) Fluid milk--SIC 2026

$$Q_2 = 0.470 - 1.49\ P_{mc} - 0.000227\ X_1 + 0.00418\ E$$

$R^2 = 0.84$ $F = 9.04$ d.f. = 6

Where: Q_2 = public water intake (gallons) divided by pounds of milk output; X_1 = plant size (K lbs./day); and E = employment.

(3) Poultry processing--SIC 2015

$$Q_3 = 16.4 - 40.6\ P_{mc} - 0.293\ X_1 + 0.022\ E$$

$R^2 = 0.59$ $F = 2.39$ d.f. = 6

Where: Q_3 = public water intake (gallons) divided by the number of birds processed; and X_1 = plant size in million birds/year. T-statistics and standard errors are not reported.

The F-statistics of the brewery and milk industries are significant at the 0.018 probability level, while poultry is fairly nonsignificant at the 0.185 levels. The elasticities are estimated as -0.3, -0.6, and -0.8 respectively. The general conclusion of this study is that industries dependent on public water utilities and having conservation and reuse alternatives will respond to water rate increases by reducing demand.

Data Base Information:

Study Area Data

Location and water users: 90 industrial plants in five four-digit SIC coded industries.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: not specified.
User sector: industrial.
Area character: not specified.

Water Use Data

Maximum number of cases: 12 cases in brewery; 10 in fluid milk, and 10 in poultry processing.
Type of measurement: secondary data from the industrial firms; rate structure information from the water utility.
Measurement period: not clearly specified (approx. 1970).
Dependent variable: public water intake (gallons per day) divided by plant output.
Estimating technique: multiple regresssion.
Price variable specification: marginal price of the last block of intake water ($/KG).

Minimum, maximum, and mean variable values and price elasticities:

Brewery--SIC 2082:
Q = 111-400; 239 gallons/barrels output.
P_{mc} = 0.093-0.820; 0.360 $/KG.
X_1 = 150-10,000; 3,614 barrels/day.
Price elasticity = -0.30 (at mean).

Fluid Milk--SIC 2026:
Q = 0.010-2.85; 0.641 gallons/lbs. milk output.
P_{mc} = 0.140-0.363; 0.206 $/KG.
X_1 = 103-7,650; 1051 K lbs./day.
E = 38-600; 171.
Price elasticity = -0.60 (at mean).

Poultry Processing--SIC 2015:
Q = 3.00-24.0; 9.42 gallons/bird.
P_{mc} = 0.080-0.300; 0.185 $/KG.
X_1 = 1.8-45.0; 15.1 million birds/year.
E = 55-500; 228.
Price elasticity = -0.80 (at mean)

46

Seidel, H. F., and E. R. Baumann. 1957. A Statistical Analysis of Water Works Data for 1955. Journal of the American Water Works Association 49(12):1531-66.

Abstract:

This article is one of the earlies studies on water demand. The study is based on 1955 American Water Works Association survey data for 480 cities. From a breakdown of water sales into residential, commercial, and industrial categories and data on the number of services in each class, mean annual water use per service was calculated. Data collected from 86 publicly owned and 25 privately owned water utilities yielded 111 cross-sectional observations of annual residential water use per service. A scatterplot indicated a correlation between residential monthly water rates and residential consumption. The author's of this study did not calculate the price elasticity from the fitted regression line. However, Howe and Linaweaver (1967) calculated elasticities from this study's data set. Residential price elasticities were found to vary from -1.0 at a price of 15 cents per 1,000 gallons to -0.12 at a price of 45 cents per 1,000 gallons.

Data Base Information:

Study Area Data

Location and water users: 111 American cities, public and private water utilities.
Mean summer temperature: N.A.
Mean summer precipitation: N.A.
Mean summer evapotranspiration: N.A.
Mean summer moisture deficit: N.A.
Water rates: mixed rates due to multi-site data.
User sector: all residential.
Area character: urban.

Water Use Data

Maximum number of cases: 111 utilities.
Type of measurement: secondary, water sales to residential accounts.
Measurement period: 1955.
Dependent variable: N.A.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: scatterplot with fitted trend lines.
Price variable specification: average price for all customers of a utility.

Minimum, maximum, and mean variable values:

Q = 29-151; 74 in 1,000 gallons/residential service/year (86 publicly owned utilities).
Q = 34-118; 80 in 1,000 gallons/residential service/year (25 privately owned utilities).

Price elasticities: -1.0 at 15 cents per 1,000 gallons to -0.12 at 45 cents per 1,000 gallons.

47 Sewell, W. R. Derrick, and Leonard Roueche. 1974. Peak Load Pricing and Urban Water Management: Victoria, B.C., A Case Study. Natural Resources Journal 14(3):383-400.

Abstract:

The purpose of this study was to test the conclusions of previous water demand studies in a particular geographic context, namely Victoria, British Columbia. Annual aggregate municipal water use data was obtained from the Greater Victoria Water District for the years 1954-70. Variables in the study included a weighted annual average price for all customers in 1961 dollars/1,000 gallons (P_{as}); annual disposable income per income tax return in 1961 dollars (I); average summer temperature (T); and average summer precipitation (F). Using the 17 time series observations, a log-linear model is estimated for annual water demand:

$$(1)\ \log Q = \underset{(0.69)}{1.656} - \underset{(4.39)}{0.395} \log P_{as} + \underset{(0.96)}{0.191} \log I + \underset{(0.58)}{0.272} \log T - \underset{(3.30)}{0.066} \log F$$

$R^2 = 0.804$ F = N.R.   N = 17   D-W = 1.67

Price and rainfall are significant at the 0.05 level for a two-tailed test; all other coefficients are below the 0.15 level. Price elasticity in the log model is calculated as -0.395. A linear model produced the following demand functions for annual water demand:

$$(2)\ Q = \underset{(1.96)}{152.62} - \underset{(4.82)}{227.16} P_{as} + \underset{(1.30)}{0.0091} I + \underset{(0.26)}{0.313} T - \underset{(2.94)}{15.84} F$$

$R^2 = 0.788$ F = N.R.   N = 17   D-W = 1.569

The constant, price, and rainfall coefficients are significant at the 0.05 level; all other coefficients are below the 0.15 level. The constant price elasticity in the logarithmic equation is -0.395. The elasticity is -0.46 at the means for the linear model. The range of price elasticities for annual water demand over the 17 year period is from -0.318 to -0.568. Regression estimates are also present in this study for peak demand, off-peak demand, and mid-peak demand. However, the results of these equations were found to be suspect and contradictory to predicted hypothesis.

Data Base Information:

Study Area Data

Location and water users: municipal water customers in Victoria, British Columbia.
Mean summer temperature: 59 degrees F.
Mean summer precipitation: 3 inches.
Mean summer evapotranspiration: 11 inches.
Mean summer moisture deficit: 9.2 inches.
Water rates: declining block.
User sector: aggregate municipal.
Area character: urban.

Water Use Data

Maximum number of cases: 17 observations.
Type of measurement: aggregate municipal sales.
Measurement period: 1954-70.
Dependent variable: annual water consumption per customer in 1,000 imperial gallons.
Summer season definition: June, July, August.
Winter season definition: not specified.
Estimating technique: multiple regression.
Price variable specification: weighted average price for all customers (1961$/1,000 imperial gallons).

Minimum, maximum, and mean variable values:

P_{as} = 0.217-0.310; 0.270 in 1961$/1000 gallons.
Q = 118.5-150-4; 134.3 in 1,000 imperial gallons/customer/year.
I = 3,444-4,368; 4,005 in 1961$.
T = 56.9-62.1; 58.9 degrees F.
F = 0.37-1.17; 0.72 inches.

Price elasticities: -0.318 to -0.568 (range); -0.395 (log with average price); -0.46 (linear with average price).

48 **Turnovsky, Stephen J. 1969. The Demand for Water: Some Empirical Evidence on Consumer's Response to a Commodity Uncertain in Supply.** Water Resources Research 5(2):350-61.

Abstract:

The purpose of this study was to determine the effects of price and the uncertainty of water supply on household and industrial water demands. Two sets of cross-sectional water use data for the years 1962 and 1965 from 19 Massachusetts towns were used in the analysis. Aggregate municipal water use in each town was split into domestic demand and industrial demand.

The theoretical demand models used in the analysis specify the dependent variable as each town's planned annual per capita use, derived from the observed use data using four different estimation methods. Uncertainty of water supply was included as an independent variable and was estimated as the variance of supply in time-series data for each town over the period 1950-65. Estimated demand equations for per capita domestic and industrial planned consumption are reported separately for different formulations of planned consumption and variance variables.

The best-fit equation for nonindustrial demand is estimated from the 1962 cross-sectional data as:

$$(1)\quad Q^* = \underset{(4.95)}{0.317\, S^2} - \underset{(3.19)}{0.779\, P_{au}} + \underset{(12.5)}{0.050\, X_1}$$

$R^2 = 0.86$ F = N.R. d.f. = 3,10

while that for the 1965 data is:

$$(2)\quad Q^* = \underset{(4.15)}{0.2945\, S^2} - \underset{(2.85)}{0.736\, P_{au}} + \underset{(10.85)}{0.051\, X_1}$$

$R^2 = 0.77$ F = N.R. d.f. = 3,12

Where: Q^* = planned nonindustrial per capita consumption (average annual) in gallons per day represented by the actual consumption during the previous year; S^2 = variance of supply calculated as the average of squared differences in water use between two consecutive years for the period 1950-65; and X_1 = index of per capita housing space obtained by dividing average number of rooms per dwelling unit by median number of occupants in each town.

The best-fit equation for industrial demand estimated from the 1962 data is:

$$(3)\quad Q^* = \underset{(0.03)}{57.8} + \underset{(8.13)}{0.894\, S^2} - \underset{(2.17)}{1.041\, P_{au}}$$

$R^2 = 0.92$ F = N.R. d.f. = 2,13

and for the 1965 data:

$$(4)\ Q^* = \underset{(4.61)}{73.8} + \underset{(7.13)}{0.777}\ S^2 - \underset{(3.03)}{1.393}\ P_{au}$$

$R^2 = 0.89$ F = N.R. d.f. = 2,15

Where: Q^* is planned per capita industrial demand, and S^2 and P_{au} correspond to those in the nonindustrial demand equations.

The price elasticities calculated at the mean values of the variables varied from -0.049 to -0.406 for nonindustrial (domestic) demand, and from -0.473 to -0.839 for industrial demand. The author reports standard errors of estimate and residual variance for each regression coefficient.

Data Base Information:

Study Area Data

Location and water users: 19 Massachusetts towns.
Mean summer temperature: 65-80 degrees F.
Mean summer precipitation: 6-8 inches.
Mean summer evapotranspiration: 14-15 inches.
Mean summer moisture deficit: 9.2-11.4 inches.
Water rates: varied due to multi-site data.
User sector: industrial/nonindustrial.
Area character: urban.

Water Use Data

Maximum number of cases: 18 cases.
Type of measurement: secondary.
Measurement period: 1962, 1965.
Dependent variable: planned annual per capita consumption (represented by the observed consumption in preceeding year).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: OLS regression.
Price variable specification: average price for all customers of utility obtained by dividing the metered revenue by the metered gallons.
Special circumstances: 1962-65 drought.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: non-industrial demand = -0.276 and -0.249; industrial demand = -0.505 and -0.631.

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49 **Ware, James E., and Ronald M. North. 1967.** **The Price and Consumption of Water for Residential Use in Georgia.** **Bureau of Business and Economic Research. School of Business Administration, Georgia State University. Atlanta.**

Abstract:

The purpose of this study was to identify and examine the factors that affect residential water consumption in 14 Georgia communities. The 14 sample areas varied in size and geographic area and were stratified by relative income levels. Water consumption and expenditure data were collected for 634 residential households, using utility records. Personal and financial characteristics of each household were obtained from interviews or mail questionnaires.

The original hypothesis was that residential water demand is a function of the following variables: number of bathrooms per household; use of a dishwasher; use of a clothes washer; ownership of an automatic lawn sprinkler or swimming pool; irrigable lawn area (1,000 square feet); market value of residence ($1,000); household income ($1,000/year); and average price for water and sewerage service per month ($/1,000 gallons). The dependent variable is the quantity of water used per household per year (1,000 gallons). "The mean value for each of the nine variables was derived for each area. These mean values were then weighted by the number of observation per city in order to reduce distributional discrepancies caused by differences among towns." Therefore, the weighted mean values for each area were utilized in the regression analysis.

The regression analysis with all nine variables using a linear stepwise model produced a R^2 of 0.90. However, only the price variable was significant at the 0.05 level, and several variables displayed incorrect signs. Since price, use of sprinkler or pool, and income accounted for 86 percent of the variation in the stepwise model, it was assumed that "price and income together quite likely explained a majority of the variation in water consumption among communities." Therefore, the regression models using only price and income are estimated as:

(1) Linear

$$Q = 66.084 - \underset{(5.01)}{53.103}\, P_{au} + \underset{(2.06)}{8.370}\, I$$

$$R^2 = 0.69 \quad F = 23.51 \quad d.f. = 11$$

(2) Double-log

$$\text{Log } Q = 1.107 - \underset{(4.68)}{0.608} \log P_{au} + \underset{(0.93)}{0.379} \log I$$

$$R^2 = 0.68 \quad F = 21.75 \quad d.f. = 11$$

Where: Q = annual water consumption per household (1,000 gallons); P_{au} = average price; and I = annual income. The values in parentheses are t-statistics. Price is significant at the 0.01 level in both models; whereas, income is significant at the 0.10 in the linear equation and insignificant at any meaningful level in the logarithmic model. Both models are significant at the 0.01 level. In the linear and logarithmic models, the price elasticity is calculated at -0.67 and -0.61, respectively.

Data Base Information:

Study Area Data

Location and water users: 634 households from 14 Georgia communities.
Mean summer temperature: 75-85 degrees F.
Mean summer precipitation: 12-18 inches.
Mean summer evapotranspiration: 16-20 inches.
Mean summer moisture deficit: 8.8-9.2 inches.
Water rates: fixed minimum demand charge with declining blocks.
User sector: residential single-family.
Area character: urban and suburban.

Water Use Data

Maximum number of cases: 14 observations.
Type of measurement: secondary data for consumption and expenditure from the water departments and household characteristics were obtained from interviews and mail questionnaires.
Measurement period: 1965.
Dependent variable: quanity of water used per household per year (1,000 gallons).
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: multiple regression.
Price variable specification: average price for water and sewage service for all customers of utility per month ($/1,000 gallons).

Minimum, maximum, and mean variable values:

Q = 28.8-149.5, 79.4 in 1,000 gallons/year.
P = 0.204-2.427,$ 0.912/1,000 gallons.
I = 5.6-10.5, $7.9 in $1,000/year).

Note: The minimum and maximum values are means from each community; the mean value is weighted by the number of observations per city.

Price elasticities: -0.61 (log) to - 0.67 (linear).

50 Wong, S. T. 1972. A Model on Municipal Water Demand: A Case Study of Northeastern Illinois. Land Economics 48(1):34-44.

Abstract:

The purpose of Wong's study of the Chicago area and 103 municipal water systems in northeastern Illinois was to evaluate economic demand for municipal water. The article presents regressions of municipal water consumption using a double-log functional form. The analysis was performed on data obtained from the City of Chicago Department of Water and Sewers; the United States Department of Commerce, Bureau of Census; and other local, state, and federal agencies. The results of time-series regressions (1951-61) produce two models: one for Chicago and the other for an aggregate of 59 Chicago suburbs. Using ordinary least squares regression the estimated equations are as follows:

(1) Chicago City

$$\text{Log } q_{it} = \text{Log } (0.89) - \underset{(1.0)}{0.02} \text{ Log } p_{it} + \underset{(2.86)}{0.20} \text{ Log } y_{it} + \underset{(3.15)}{0.41} \text{ Log } s_{it}$$

$R^2 = 0.82$ $F = 10.44$ $df = 3,7$ $Se = 0.00434$

(2) Outside communities

$$\text{Log } q_{it} = \text{Log } (-0.58) - \underset{(3.50)}{0.28} \text{ Log } p_{it} + \underset{(1.00)}{0.26} \text{ Log } y_{it} + \underset{(2.73)}{1.26} \text{ Log } s_{it}$$

$R^2 = 0.57$ $F = 3.14$ $df = 3,7$ $Se = 0.01560$

Where: q_{it} = average per capita water demand of municipality i in year t; p_{it} = price of water for municipality i, in cents per 1,000 gallons, in year t; y_{it} = average household income in municipality i in year t; and s_{it} = average summer temperature for municipality i in year t. Price is found to be insignificant (elasticity -0.02) for Chicago, whereas, it is significant at the 5 percent level for outside communities (elasticity -0.28). In both demand functions, average summer temperature have the most significant effect on the equation and the multiple R's. The author suggests that a uniform rate structure and otherwise very low price of water is responsible for the insignificant effect of price on water use in Chicago.

Four cross-sectional regressions of residential per capita water use are performed for the 103 municipal water systems (stratified into four community size groups). The estimated equations for the four groups from 1961 data are:

(1) 25,000 and over

$$\text{Log } q_{it} = \text{Log } (-1.45) - \underset{(2.30)}{0.53} \text{ Log } p_{it} + \underset{(3.43)}{1.03} \text{ Log } y_{it}$$

$R^2 = 0.48$ $F = 9.34$ $df = 2,20$ $Se = 0.093$

(2) 10,000-24,999

$$\text{Log } q_{it} = \text{Log } (-0.18) - \underset{(5.47)}{0.82} \text{ Log } p_{it} + \underset{(2.71)}{0.84} \text{ Log } y_{it}$$

$R^2 = 0.53$ $F = 21.13$ $df = 2,37$ $Se = 0.146$

(3) 5,000-9,999

$$\text{Log } q_{it} = \text{Log } (-0.67) - \underset{(1.00)}{0.46} \text{ Log } p_{it} + \underset{(1.00)}{0.48} \text{ Log } y_{it}$$

$R^2 = 0.38$ $F = 6.65$ $df = 2,22$ $Se = 0.099$

(4) 4,999 and less

$$\text{Log } q_{it} = \text{Log } (-0.14) - \underset{(1.52)}{0.26} \text{ Log } p_{it} + \underset{(1.21)}{0.58} \text{ Log } y_{it}$$

$R^2 = 0.30$ $F = 2.52$ $df = 2,12$ $Se = 0.082$

The price elasticities for the four community-size groups are -0.53, -0.82, -0.46, and -0.26 (from largest to smallest group). The price elasticities are significant at the 0.05 level except for the smallest community-size group. Furthermore, all the price elasticity coefficients are larger in the cross-sectional analysis than in the time series analysis. The author suggests that this may be due to the higher costs involved in utilizing ground water as a supply source. Whereas, the water supply source for Chicago and her surrounding communites is the surface water from Lake Michigan, ground water is the source for the 103 communities.

All the regression equations, except for the smallest community size group had significant variance-ratios (F-values). The data characteristics are not discussed in detail. Furthermore, the small sample sizes in both parts of the study may have biased the results. The price elasticity and income elasticity values of this study are compared with the results of 17 previous studies of these variables.

Data Base Information:

Study Area Data

Location and water users: Chicago, Illinois, and surrounding communities.
Mean summer temperature: 71 degrees F.
Mean summer precipitation: 10-12 inches.
Mean summer evapotranspiration: 16 inches.
Mean summer moisture deficit: 9.4 inches.
Water rates: uniform.
User sector: aggregate municipal.
Area character: urban, suburban.

Water Use Data

Maximum number of cases: 11 for time-series analysis; 23, 40, 25, 15 for largest to smallest communities for cross-sectional analysis.
Type of measurement: aggregate water sales.
Measurement period: time series: 1951-61; cross-sectional: 1961.
Dependent variable: average per capita water demand of municipality.
Summer season definition: June, July, August.
Winter season definition: not specified.
Price variable specification: average price for all customers in utility.
Estimating technique: ordinary least squares regression.
Special circumstances: none specified.

Minimum, maximum, and mean variable values: no variable values reported.

Price elasticities: Chicago = -0.02; outside communities = -0.28; and -0.53, -0.82, -0.46, and -0.26 for largest to smallest community size groups.

51 Young, C. E., K. R. Kinsley, and W. E. Sharpe. 1983. Impact on Residential Water Consumption of an Increasing Rate Structure. Water Resources Bulletin 19(1):81-86.

Abstract:

This paper evaluates the impact of an increasing step rate structure on residential household water use. The study was conducted from data supplied by the Washington Suburban Sanitary Commmision (WSSC) which serves the Maryland portion of the Washington, D.C., metropolitan area. In January 1978, the WSSC changed from a uniform rate structure to an increasing step rate structure. The authors stress that the "new rate structure differs from increasing-block rate systems in that it requires that the increased rate be paid on all water used in the billing period and not just on the last increment used in excess of the previous amount."

The WSSC supplied quarterly water use data from 1974 through 1979 for 545 single family residential customers. In order to evaluate the impact of implementing the increasing rate structure, "demand functions are estimated for the before rate change period" using pooled time series and cross-sectional data. However, since the real price of water was relatively constant during this time period (1974-77), the model is calculated without the price variable. The procedure used to estimate the impact of the rate structure change was to "deduct actual water use in 1978 and 1979 from predicted use based on pre-1978 consumption patterns."

Using an error components regression procedure (SAS Institute, Inc.), demand functions are estimated for low, medium, and high user groups. The estimated prediction equations are:

(1) Low user group (less than 13,500 gallons per quarter)

$$Q = \underset{(2.61)}{5.34} + \underset{(1.27)}{0.00008Y} + \underset{(4.47)}{1.84H} - \underset{(-4.72)}{0.63X_1} + \underset{(2.46)}{1.01X_2} + \underset{(2.25)}{0.93X_3} - \underset{(-1.79)}{0.74X_4}$$

$$+ \underset{(1.58)}{1.51X_5} + \underset{(0.85)}{0.94W}$$

Df = 1447 Mean Square Error = 26.09

Average water use = 11.81 (1,000 gallons per quarter)

(2) Medium user group (13,500-24,000 gallons per quarter)

$$Q = \underset{(5.89)}{8.90} + \underset{(4.19)}{0.00013Y} + \underset{(7.67)}{1.72H} - \underset{(-2.13)}{0.39X_1} + \underset{(5.27)}{3.01X_2} + \underset{(4.82)}{2.75X_3} + \underset{(0.03)}{0.02X_4}$$

$$+ \underset{(0.45)}{0.33X_5} + \underset{(2.40)}{2.16W}$$

Df = 3223 Mean Square Error = 44.90

Average water use = 21.29 (1,000 gallons per quarter)

(3) High user group (greater than 24,000 gallons per quarter)

$$Q = \underset{(4.07)}{16.80} + \underset{(3.65)}{0.00024Y} + \underset{(2.01)}{0.90H} - \underset{(-1.38)}{0.32X_1} + \underset{(7.60)}{5.51X_2} + \underset{(7.12)}{5.16X_3}$$

$$+ \underset{(1.53)}{0.85X_4} + \underset{(0.41)}{1.17W}$$

Df = 1655 Mean Square Error = 99.97
Average water use = 35.32 (1,000 gallons per quarter)

Where: Q = quarterly household water use (gallons); Y = assessed house value (\$); H = household size; X_1 = trend (1974 = 1...1977 = 4; included because of conservation programs); X_2 = spring (April, May, June) dummy; X_3 = summer (July, August, September) dummy; X_4 = fall (October, November, December) dummy; X_5 = use of water conservation devices; and W = use of dishwashers. Values in parantheses are t-statistics.

Actual water use for 1978 and 1979 was than subtracted from predicted usage for each household. The mean change in water use is presented for user groups seasonally and annually. "Water use declined in 1978 and 1979 in all instances except for low users in the fall quarters and high users in the winter quarters, neither of which are significantly different from zero. The reductions in water use are larger for the spring and summer quarters than for the fall and winter quarters, indicating a more elastic demand for water during the spring and summer months. Also, in all cases except for low users in the winter quarter, the reductions in water use increase from 1978 to 1979. The greater reaction to the rate structure in 1979 may in part be attributed to a time lag necessary for consumers to react to the new rate structure." Therefore, it is concluded that the increasing step rate structure caused a reduction in water use for medium and high user groups. Estimated reductions in water use ranged from 1.1 to 8.7 percent.

Data Base Information:

Study Area Data

Location and water users: 545 customers in the Washington Suburban Sanitary District, Maryland.
Mean summer temperature: 75 degrees F.
Mean summer precipitation: 10 inches.
Mean summer evapotranspiration: 18 inches.
Mean summer moisture deficit: 12 inches.
Water rates: uniform to increasing step rate (not block).
User sector: residential single-family.
Area character: suburban.

Water Use Data

Maximum number of cases: 13,080 observations.
Type of measurement: secondary measurements for individual users.
Measurement period: 1974-79 (24 periods: 16 before the rate change and 8 after).
Dependent variable: household quarterly use (gallons).

Summer season definition: July, August, September.
Winter season definition: January, February, March.
Price variable specification: not applicable.
Estimating technique: error components regression.
Special circumstances: water conservation programs with massive public education and distribution of conservation devices.

Minimum, Maximum, and mean variable values:

Mean Q = low users: 11,810 (gallons per quarter); medium users: 21,290; high users: 35,320. No other variable values reported.

Price elasticity: not reported.

52

Young, Robert A. 1973. Price Elasticity of Demand for Municipal Water: A Case Study of Tucson, Arizona. Water Resouces Research 9(4):1068-72.

Abstract:

This article presents estimates of the price elasticity of aggregate water use for Tucson, Arizona, from time-series data for a single utility. The Tucson water utility supplied data on water production, charges, and the number of active services for the utility from 1946 through 1971. However since the utility did not distinguish between user class (until later years), the data are in aggregate form. Climatic data were obtained from the U.S. Weather Bureau and income data were derived from state revenue reports.

An analysis of variance test indicated that equations obtained for two subperiods (1946-64 and 1965-75) were not derived from the same demand relationship, therefore regression results of the two subperiods were reported separately. The estimated equations in linear and logarithmic forms for both subperiods are presented below:

(1) 1946-1964

(a) $$Q = 489.07 - \underset{(2.46)}{687.39}\, P_{as} - \underset{(2.02)}{3.99}\, F$$

$R^2 = 0.56$ N = 19 F = N.R.
Price elasticity = -0.65 (at mean)

(b) $$\text{Log } Q = \text{Log } 5.09288 - \underset{(2.31)}{0.60}\, \text{Log } P_{as} - \underset{(2.00)}{0.14}\, \text{Log } F$$

$R^2 = 0.60$ N = 19 F = N.R.
Price elasticity = -0.60 (constant)

In both forms the P_{as} coefficient is significant at 0.05 level and the F coefficient is significant at 0.10 level of the t-test.

(2) 1965-1971

(a) $$Q = 373.61 - \underset{(2.01)}{316.61}\, P_{as} - \underset{(1.01)}{0.87}\, F$$

$R^2 = 0.64$ N = 7 F = N.R.
Price elasticity = -0.41 (at mean)

(b) $$\text{Log } Q = \text{Log } 5.17312 - \underset{(1.86)}{0.41}\, P_{as} - \underset{(0.75)}{0.03}\, F$$

$R^2 = 0.60$ N = 7 F = N.R.
Price elasticity = -0.41 (constant)

In both forms (1965-71) the price variable coefficients were not significantly different from each other at the 0.10 level. In the equations Q = annual water production per active service (1,000 gallons), P_{as} = average price ($/1,000 gallons), and F = precipitation (inches per year). The author notes that the insignificant coefficients of the second subperiod are the result of the short time period (N = 7). A later reanalysis of the complete data set (Carver, Ph.D. diss., 1978) indicated a short-run price elasticity of -0.2 (significant at 0.10 level), for the full 1946-71 period.

Data Base Information:

Study Area Data

Location and water users: aggregate users of Tucson Water Utility, Arizona.
Mean summer temperature: 86 degrees F.
Mean summer precipitation: 5 inches.
Mean summer evapotranspiration: 21 inches.
Mean summer moisture deficit: 18 inches.
Water rates: declining block with minimum service charge.
User sector: aggregate municipal (principally residential users).
Area character: urban.

Water Use Data

Maximum number of cases: 26 observations.
Type of measurement: aggregate water production records.
Measurement period: 1946-71.
Dependent variable: annual water production per active service (1,000 gallons).
Estimating technique: ordinary least squares regression (stepwise).
Price variable specification: average price ($/1,000 gallons) calculated as a mean for all users in sample.
Special circumstances: significant rate change in 1965 caused a shift in demand.

Minimum, maximum, and mean variable values:

Q = 236-326; 268 in 1,000 gallons/active service/year).
P_{as} = 0.22-0.36; 0.27 average charge/1,000 gallons.
F = 5.7-15.6; 10.49 inches/year.

Price elasticities: -0.41 to -0.65.

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53 Ziegler, Joseph A., and Stephen E. Bell. 1984. Estimating Demand for Intake Water by Self-Supplied Firms. Water Resources Research 20(1):4-8.

Abstract:

The purpose of this study was to select the proper specification of the price variable for estimating the demand of intake water by self-supplied industrial firms. The null hypothesis is that there is no significant difference in the estimates of industrial water demand, using either average or marginal costs. This hypothesis was tested by utilizing cross-sectional data from a questionnarire of 23 high-volume water-using paper and chemical firms.

Although these firms pay for the acquisition, treatment, and disposal of water; they do not face a market price because of the self-supplied water. Therefore, the average cost of intake water is used as a proxy, since that is the price generated by input demand and supply within the firm. An approximation of marginal cost was calculated by first estimating a total cost of intake water function using regression analysis and then differentiating with respect to the quantity of intake water to obtain an estimate of the marginal cost function.

Using an exponential form (log transformations) the following demand models are estimated:

(1) Marginal price model

$$\log Q = \underset{(9.66)}{2.81} \log 10 + \underset{(3.31)}{0.0001}\, P_{mc} - \underset{(-2.11)}{1.89} \log X_1$$

R^2adj. = 0.63 F = 9.55 N = 23

(2) Average price model

$$\log Q = \underset{(9.65)}{5.41} \log 10 - \underset{(-2.28)}{0.078}\, P_{ac} - \underset{(-3.22)}{2.51} \log X_1 - \underset{(-3.98)}{1.56} \log X_2$$

R^2adj. = 0.76 F = 10.61 N = 23

Where: Q = the amount of water extracted to produce output in terms of thousands of gallons per day; P_{mc} = the marginal cost of obtaining, treating, and disposing intake water in cents per thousand gallons of intake water; P_{ac} = average cost of intake water in cents per 1,000 gallons; X_1 = dummy variable obtained by assigning 0 to old levels of technology and 1 to all other levels; and X_2 = dummy variable for type of plant, where paper = 0 and chemical = 1. T-values are in parentheses and indicate that all independent variables are significant at the 0.001 level. The average cost variable displayed the expected negative sign, while marginal cost did not.

Although both P_{ac} and P_{mc} are significant, their coefficients are different in both sign and magnitude. Therefore, the null hypothesis could not be accepted, i.e., the selection of P_{ac} and P_{mc} resulted in different water use models. It was concluded that the use of average

costs tends to result in a model with a better statistical fit and predictive capability rather than in a model using marginal cost for self-supplied industries. The use of marginal cost as a price surrogate established an unexpected positive dependence between cost and quantity, suggesting that a supply, rather than a demand, relationship was estimated. At the mean average price, the elasticity would be calculated at -0.98.

Data Base Information:

Study Area Data

Location and water users: 23 paper and chemical firms in Arkansas.
Mean summer temperature: 75-80 degrees F.
Mean summer precipitation: 10 inches.
Mean summer evapotranspiration: 18-20 inches.
Mean summer moisture deficit: 12-14 inches.
Water rates: N.A.
User sector: industrial.
Area character: not specified.

Water Use Data

Maximum number of cases: 23 observations.
Type of measurement: mail questionnaire of the selected industries.
Measurement period: not specified (assume late 1970s).
Dependent variable: amount of intake water obtained from all sources in gallons per day.
Summer season definition: not specified.
Winter season definition: not specified.
Estimating technique: OLS stepwise regression.
Price variable specification: marginal price and average price (see text for specifications).
Special circumstances: self-supplied firms.

Minimum, maximum, and mean variable values:

Q = mean: 11,390.36 in 1,000 gallons/day.
P_{ac} = 9-21; 12.6 cents/1,000 gallons.
P_{mc} = mean: 22.78 cents/1,000 gallons.
X_1 = mean: 0.83.
X_2 = mean: 0.64.

Price elasticities: -0.98 (mean average price).

TABLE A-1. DESCRIPTION OF DATA BASES BY ABSTRACT NUMBER

Abstract Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. User Sector:																		
Aggregate municipal		X							X		X						X	
Residential single-family							X	X		X			X					
Residential multi-family																		
All residential	X				X	X						X						X
Commercial																		
Industrial				X										X	X	X		
All uses except industrial			X															
2. Study Area Characteristics:																		
Single area	X				X	X		X		X	X		X					
Multiple sites		X	X	X			X		X			X		X	X	X	X	X
Mean summer temperature, deg. F	85	65-75	76	76	86	86	75-80	75	75	65	75	70-80	77	70-75	--	--	--	--
Mean summer precipitation, in.	5	0-2	1-14	1-14	5	5	10	10	10	1	9	0-1	16	6	--	--	--	--
Mean summer evapotranspiration, in.	21	9-15	17-20	17-20	27	27	19	3	18	9	15	10-15	17	14	--	--	--	--
3. Data Set Configuration:																		
Time series	X				X	X					X							
Cross-sectional		X	X	X			X			X		X		X	X		X	X
Pooled time series and cross-sect.								X	X				X			X		
Period of measurement	74-77	55-56	78	78	74-77	74-77	70s	74-76	69-74	70-75	69-70	55	69-74	65	57-70	60s	55	60
4. Identification of Dependent Variable:																		
Monthly use	X				X	X				X	X		X					
Summer/winter division																		
Seasonal/non-seasonal			X					X	X									
Annual		X		X			X					X		X	X	X	X	X
5. Price Variable Specification:																		
Average price		X	X	X			X					X		X			X	X
Marginal price	X				X	X	X	X	X	X	X		X		X	X		
Nordin's bill difference	X				X	X	X											
6. Water Rates:																		
Uniform price								X		X			X					
Decreasing block			X												X			
Increasing block	X				X	X	X		X									
Mixed rates (multi-site)		X										X		X			X	X
Other				X							X					X		

TABLE A-1. DESCRIPTION OF DATA BASES BY ABSTRACT NUMBER (continued)

Abstract Number	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. User Sector:																		
Aggregate municipal			X			X						X						
Residential single-family		X			X			X		X	X			X			X	
Residential multi-family																		
All residential	X			X					X				X		X	X		
Commercial																		X
Industrial							X											
All uses except industrial																		
2. Study Area Characteristics:																		
Single area					X					X	X	X		X			X	X
Multiple sites	X	X	X	X		X	X	X	X				X		X	X		
Mean summer temperature, deg. F	—	—	65	60-70	82	74-77	--	60-65	72-76	65	—	65	--	72	—	--	65-70	82
Mean summer precipitation, in.	—	—	1-3	10-14	28	8-12	—	8-10	8-12	7	—	3	--	15	—	—	6-8	28
Mean summer evapotranspiration, in.	—	—	15-17	13-17	19	17-20	--	13-14	14-18	14	—	16	--	17	—	--	14-15	19
3. Data Set Configuration:																		
Time series										X		X						
Cross-sectional	X		X	X		X	X	X	X				X		X	X	X	X
Pooled time series and cross-sect.		X			X						X			X				
Period of measurement	55	74-75	62	75	73-74	52-57	73	67	70	55-68	71-78	61-77	60	71-73	60	60s	76	--
4. Identification of Dependent Variable:																		
Monthly use					X							X						X
Summer/winter division																		
Seasonal/non-seasonal															X	X		
Annual	X		X	X		X	X	X	X				X				X	
5. Price Variable Specification:																		
Average price			X		X	X	X					X					X	
Marginal price	X	X		X	X			X	X		X		X	X	X	X	X	X
Nordin's bill difference																	X	
6. Water Rates:																		
Uniform price		X						X			X	X						
Decreasing block														X				
Increasing block																		
Mixed rates (multi-site)	X		X	X	X	X			X	X			X		X	X	X	X
Other							X											

TABLE A-1. DESCRIPTION OF DATA BASES BY ABSTRACT NUMBER (continued)

Abstract Number	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
1. User Sector:																	
Aggregate municipal		X		X							X			X		X	
Residential single-family			X		X	X	X						X		X		
Residential multi-family																	
All residential	X									X							
Commercial																	
Industrial								X	X			X					X
All uses except industrial												X			X		
2. Study Area Characteristics:																	
Single area			X		X						X				X	X	
Multiple sites	X	X		X		X	X	X	X	X			X	X			X
Mean summer temperature, deg. F	62-70	—	68	60-70	65-70	75-80	78	—	—	--	59	65-80	75-85	71	75	86	75-80
Mean summer precipitation, in.	4-9	—	0	0-1	6-8	14-18	10-12	—	—	--	3	6-8	12-18	10-12	10	5	10
Mean summer evapotranspiration, in.	10-16	—	11	10-18	14-15	17-19	18-20	—	--	--	11	14-15	16-20	16	18	21	18-20
3. Data Set Configuration:																	
Time series			X								X			X		X	
Cross-sectional	X	X			X	X	X	X	X	X		X	X	X			X
Pooled time series and cross-sect.				X											X		
Period of measurement	65-70	20-24	67-72	70	76	65-71	71	65	70s	55	54-70	60s	65	51-61	74-79	46-71	70s
4. Identification of Dependent Variable:																	
Monthly use			X	X			X										
Summer/winter division																	
Seasonal/non-seasonal																	
Annual	X	X			X	X		X	X	X	X	X	X	X		X	X
5. Price Variable Specification:																	
Average price	X		X	X		X	X	X		X	X	X	X	X		X	X
Marginal price					X				X								X
Nordin's bill difference																	
6. Water Rates:																	
Uniform price														X	X		
Decreasing block			X			X	X				X		X			X	
Increasing block																	
Mixed rates (multi-site)	X			X	X			X		X		X					
Other																	

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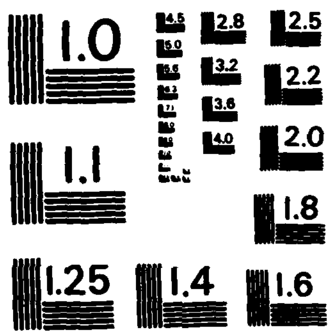

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